DAVIS STRAIT

ICEBERG SCOURING STUDY

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This C-CORE report is a synthesis of an earlier report submitted under contract #FPO 65216, to Canterra Energy Ltd., of Calgary, Alberta - operators of the Baffin-Labrador Group. The Baffin-Labrador group consists of Home Oil Ltd., Hudson Bay Oil and Gas Ltd. (now Dome), Murphy Oil Ltd., Pan-Canadian Petroleum Ltd., Petro-Canada Exploration Inc., and SOQUIP.

Technical Report
C-CORE Publication No. 84-4
December 1984

C-CORE

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The Centre for Cold Ocean Resources Engineering (C-CORE) was established at Memorial University in St. John's in 1975. Its initial funding was provided by the Devonian Group of Charitable Foundations of Calgary. Ongoing funding now comes from government and industry.

The Centre's mandate is to undertake research that will assist the safe and orderly development of Canada's resources in cold and ice frequented oceans.

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ISBN: 0-88901-122-2

ACKNOWLEDGEMENTS

This study is a joint program of the Geological Survey of Canada of the Atlantic Geoscience Centre (AGC) Dartmouth and C-CORE. Cruise planning and organization during survey HU81-045 were coordinated by Drs. C.F.M. Lewis and C. Schafer of AGC. Mr. H. Westergard of Canterra Energy, actively encouraged the research program, which was also supported financially by Canterra Energy Ltd. of Calgary. The authors thank the technical staff of AGC and the Captain and crew of CSS **HUDSON** for their invaluable assistance during the survey, and thank Dr. C.F.M. Lewis and Mr. B. MacLean of AGC for beneficial discussions and exchange of views. Linda Davis is thanked for her assistance with the illustrations, as are Rosalie Murphy, Cavell Lawlor and Gail Greenslade for meticulously typing various drafts of this report. Eleanor Nesbitt-Friis pepared the report for publication.

ABSTRACT

At the Hekja wellsite area, a multi-purpose geological survey was conducted from the Bedford Institute of Oceanography (BIO) research vessel, CSS **HUDSON**.

Two iceberg scour mosaics were compiled from sidescan sonar records of the Hekja Wellsite and Hekja North areas. Iceberg cross-cutting relationships (as defined from the mosaics) were then examined to determine the relative ages and scour depths of the individual scours. Eight relative age groups of scours have been identified from both the Hekja Wellsite and the Hekja North mosaic areas. In the deeper Hekja Wellsite area, one oldest (group 8) and three youngest (group 1) scours have been identified whereas in the shallower Hekja North area, one oldest (group 8) and two youngest (group 1) scours have been identified. Mean scour depth for the Hekja Wellsite is 1.10 m, shallower than the 1.27 m for Hekja North.

The HUNTEC DTS and airgun seismic profiles along with the sidescan sonograms identified a seabed feature at 320 m located above and adjacent to a well-defined, major geological contact zone. Its similarities to other worldwide occurrences led Woodworth-Lynas (1983a) to identify the feature tentatively as a mud volcano. Farther south on line A, at the same contact, a not dissimilar conical feature is recorded which is interpreted as an eroded, relict feature, not directly a consequence of any form of tectonism.

Underwater camera photographs illustrate the contrasting seabed sediment surface textures between the shallower and deeper areas of the survey site as well as that within the deep water area. Sediment analysis of the surface grab samples indicates coarser and predominantly biogenic sediment toward the shore with the proportion of fine-grained siliciclastic sediment increasing with water depth.

Micropalaeontological and sediment analyses of two cores suggest a number of possible causes to explain geological events recorded in the cores. The results suggest that core #44 was probably cored from either the trough, the berm, or from an area immediately adjacent to a scour. Based on the data collected, the age of the scouring event recorded in the core is not older than 5000 years BP, and not younger than 2000 years BP.

Plots of iceberg movement from an iceberg log were made and these indicate a highly variable and contrasting drift pattern between the individual icebergs. The observed drift patterns may be a response to more than one localized current regime in the area. One iceberg was inferred to have grounded in about 135 m of water.

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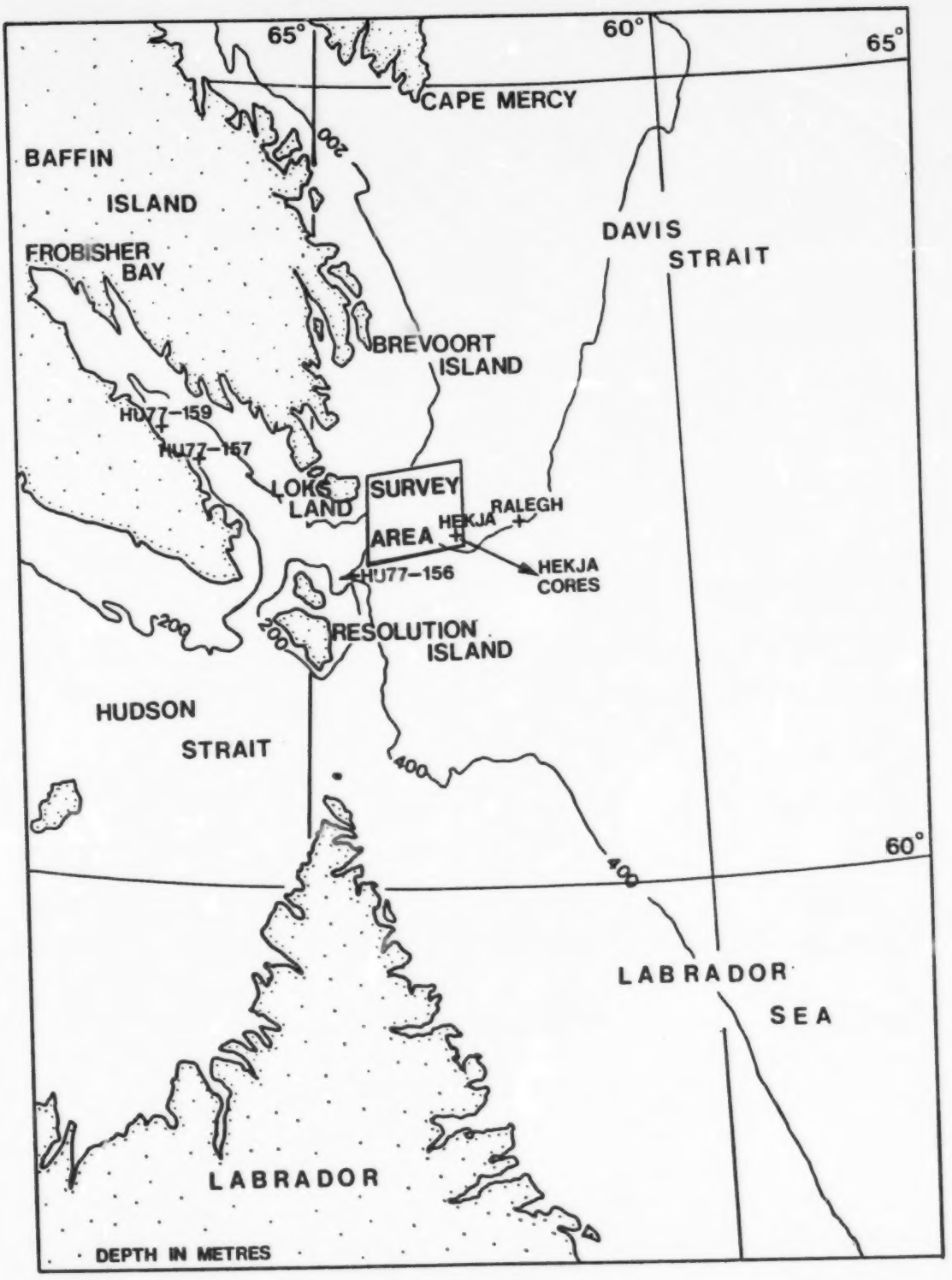


Figure 1 Location map illustrating the survey area and the positions of cores examined by Osterman (1982).

INTRODUCTION

Canterra Energy Ltd. (formerly Aquitaine Company of Canada Ltd.) has been operating in the marine area southeast of Loks Land, and has recently completed drilling the Ralegh site (Figure 1), during the 1982 drilling season. In 1980, Geonautics Ltd., was contracted by Canterra Energy Ltd., operator for the Baffin-Labrador Group, to undertake a seabed sidescan and shallow seismic survey of the Hekja Wellsite area (Geonautics, 1980a; 1980b; 1981). The survey showed iceberg scours were a common occurrence at the depth at which drilling was to be undertaken, i.e. 350 m. This result was surprising, since iceberg scour features had not been positively identified at these depths, although evidence for their existence at these depths had been reported in the literature from the Labrador Shelf (Harris, 1974; Harris and Jollymore, 1974).

Prior to drilling in this area of the Davis Strait, it was anticipated that icebergs would be encountered of similar size to those observed in earlier drilling programs off the Labrador Coast. The icebergs were not expected to have draughts of 350 m as implied by the Geonautics survey results (1980a; 1980b; 1981). The occurrence of scours to 350 m suggested that icebergs of these very large dimensions might indeed occur in this area (during the present time). This necessitated a re-evaluation of the probable size of icebergs which could drift into the area.

Alternatively, these deep water iceberg scours may be relict features from an earlier geological period and are perhaps evidence for the onset of a previous warm interglacial period(s),

when the ice sheets would have undergone increased calving at their oceanic margins and discharged large icebergs with sufficient draughts to generate the scours; this would be coupled with relatively lower sea levels. It may also be possible that aperiodic surging from rapidly receding Arctic/Greenland glaciers during the present time could produce very large icebergs with draughts in excess of 300 m. A further suggestion is that the scours could have been made by smaller icebergs when the sea level in this area was much lower due either to eustatic (sea level) and/or isostatic (tectonic adjustments) equilibrium changes.

It is worthwhile to note here that Icebergs and Ice Islands which have draughts in excess of 300 m are a common occurrence in the Antarctic waters, whereas only a very few have been reported for the Arctic regions. Large Arctic icebergs which have been reported from Greenland fjords rarely escape due to sills at the mouth of the fjords.

OBJECTIVES

The objectives of the program which have been detailed in Barrie 'et al.', (1982) and briefly restated here, are:

(1) to re-examine the earlier surveyed site,

(2) to date the scours relative to each other,

(3) to sample the sediments in order to determine the genesis and mobility of the surficial cover,

(4) to obtain cores from the area and examine them radiographically, and finally

(5) to analyse the foraminifera and sediments from the cores to establish a depositional chronology.

While this study will address the above objectives, it will be concerned primarily with an attempt to determine the age of iceberg scours, both in relative and in absolute terms. Relative dating techniques used were iceberg cross-cutting relations and frequency distribution ('vide' Woodworth-Lynas, 1983b). The absolute dating technique involves the radiometric dating of biogenic material from cores collected from within a scour (Figure 2).

To determine the absolute age and relationship between scours within the area exhibited by the sidescan mosaic, it is a prerequisite that cores are collected from predetermined oldest and youngest scours (previously identified using relative dating techniques). The cores are then dated radiometrically - the scouring event being recognized using the technique illustrated in Figure 2. However, given the available facilities, it is not feasible to carry out the field work implied above and hence it

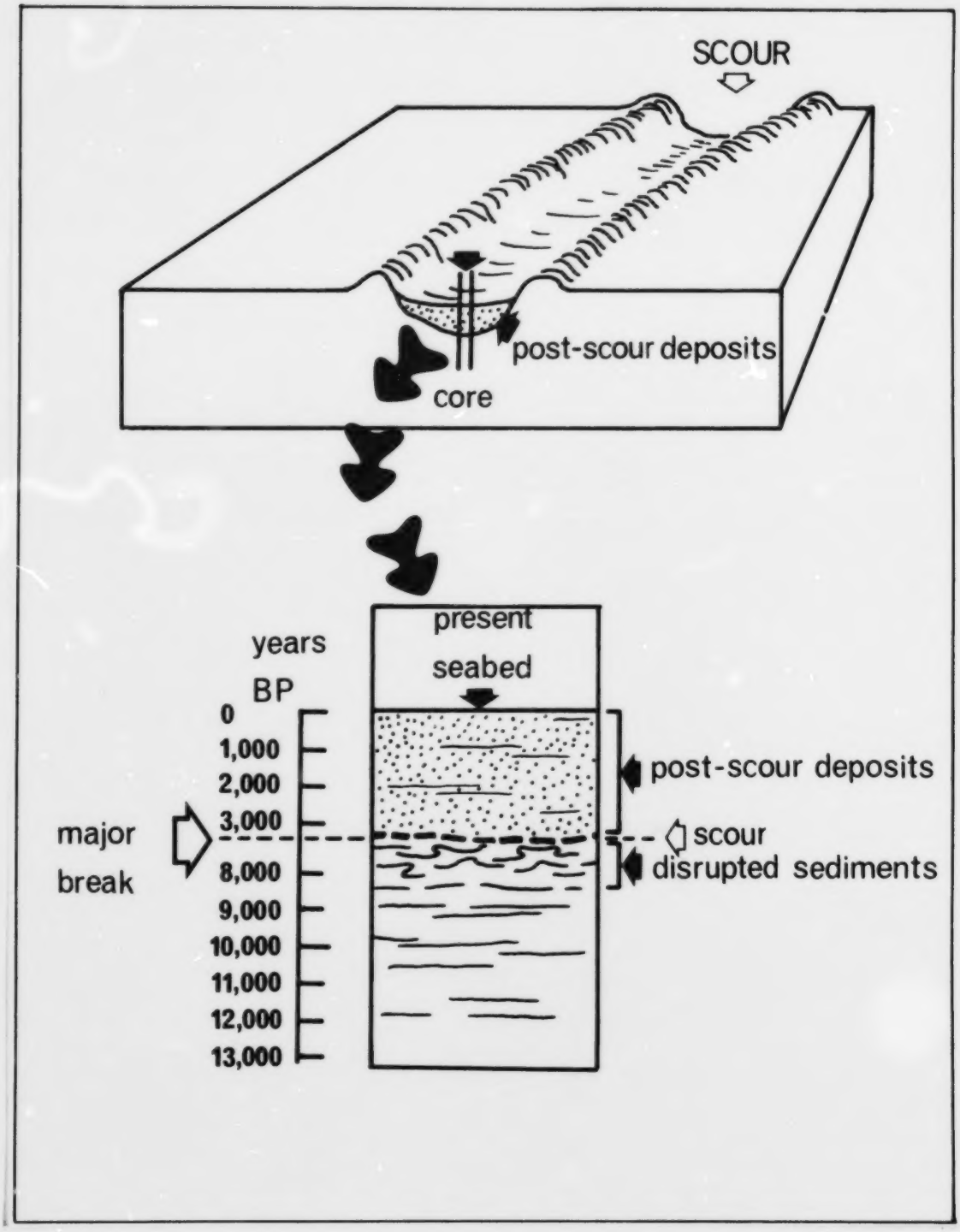


Figure 2 Simplified theoretical block diagram to illustrate how a core taken from a scour through can be used to date the age of the scour using micropalaeontological (and radiometric) techniques.

is necessary to follow an alternative and equally acceptable approach.

The approach taken here is to obtain a detailed depositional history from a number of cores from the vicinity of the wellsite and to bracket the temporal history of the individual cores using radio-carbon 'absolute' dates; cross-correlation with the other collected cores can then be attempted using amino-acid derived D/L (allo/iso) ratios of the fossils in each core. Cross-correlation between the cores would assume constant, unvaried sedimentation for this area of the shelf as well as an established micropalaeontological stratigraphy for both the onshore and marine areas.

Further, knowledge of sea level variations during this period will throw significant light on the probable maximum size of icebergs that drifted into the area during the time interval represented in the cores examined.

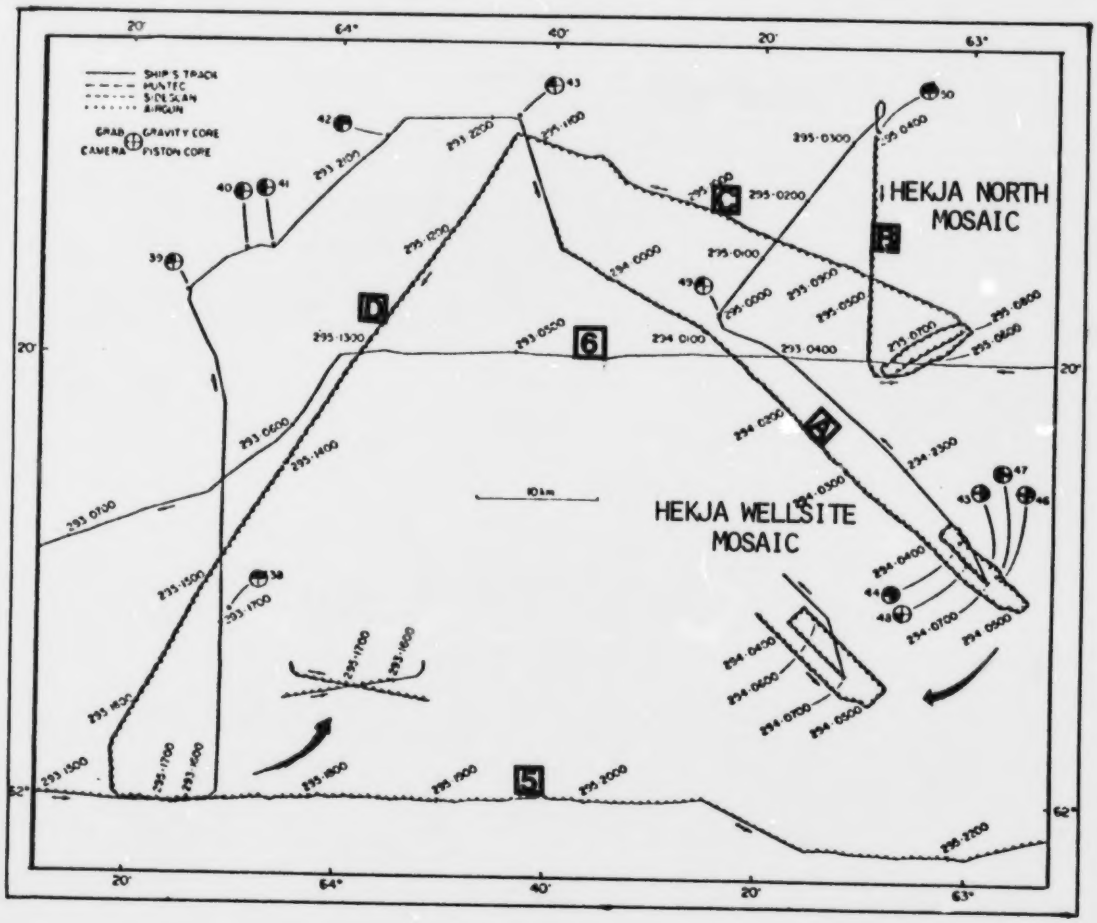


Figure 3 Map showing survey lines, sidescan sonar mosiac surveys and sample and camera locations. Survey lines identified by letters or numbers in boxes.

SUMMARY OF DATA COLLECTED

Sidescan

A BIO 70 kHz medium-range sidescan sonar system with a variable slant range between 350 m to 750 m (total swath 700 m to 1500 m) was used for the survey. Over 209 km of data were collected from the four survey lines and two sidescan mosaic surveys (Figure 3). The mosaic surveys were at the Hekja Wellsite and Hekja North (Figures 4 and 5). At water depths between 190 m and 260 m, the sidescan fish was towed at a depth of about 105 m, and at a ships' speed of 6.5 knots. At greater water depths of 350 m and a fish depth of 260 m, the speed was rarely more than 3.5 knots.

Airgun seismics

A 40 cu. in. (= 657 cm^3) airgun was used in the collection of single channel reflective seismic data. Within the Hekja vicinity about 104 km of data were collected along lines A, B, C and D (Figure 3) and a further 111 km of data were collected from multiparameter line #5.

Huntec DTS seismics

Approximately 209 km of data were collected. However, due to its repeated malfunctioning during the transects, use of the Huntec system to determine sediment thickness was intermittent.

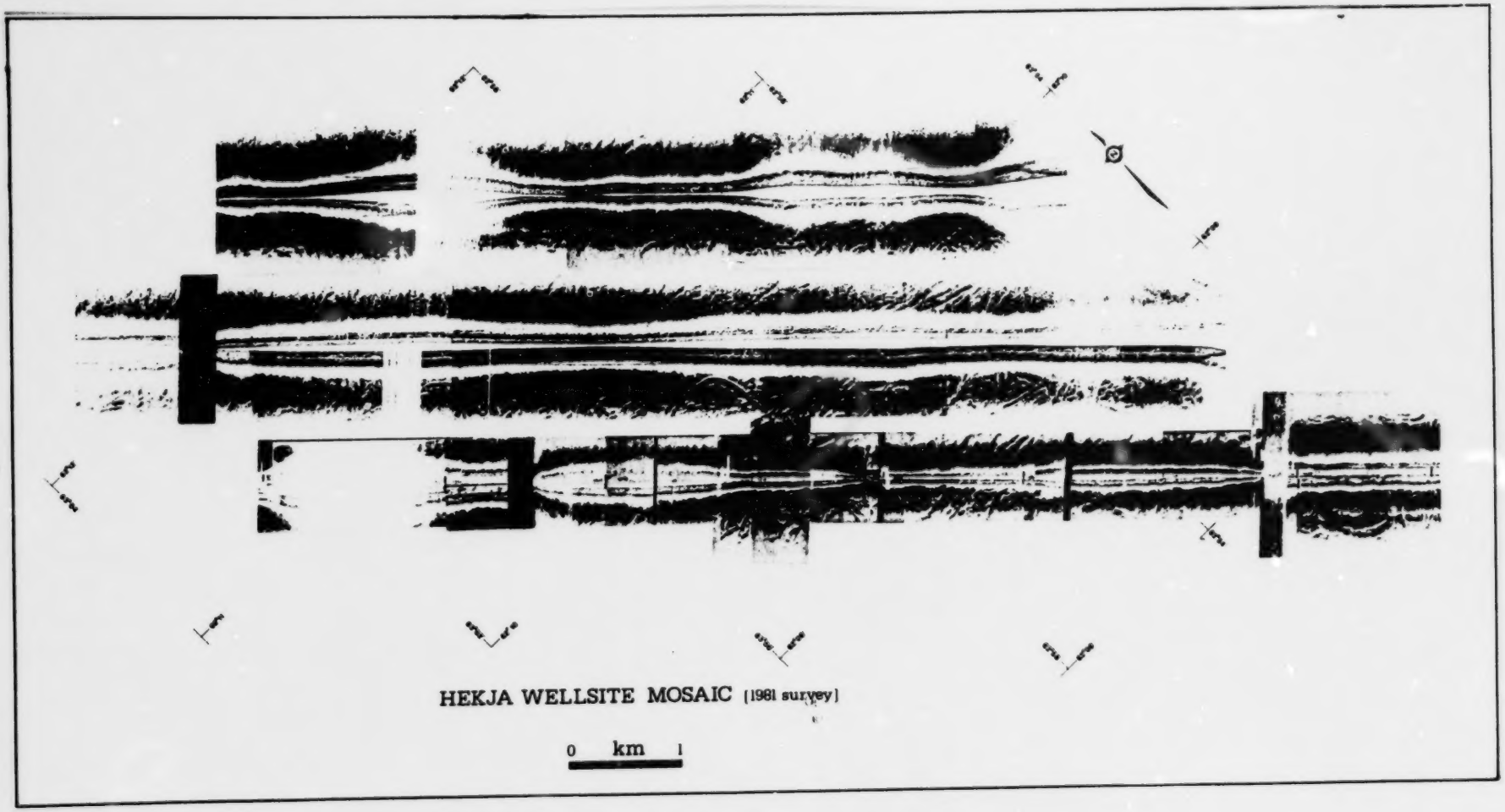


Figure 4 Hekja Wellsite mosiac constructed from BIO sidescan data.

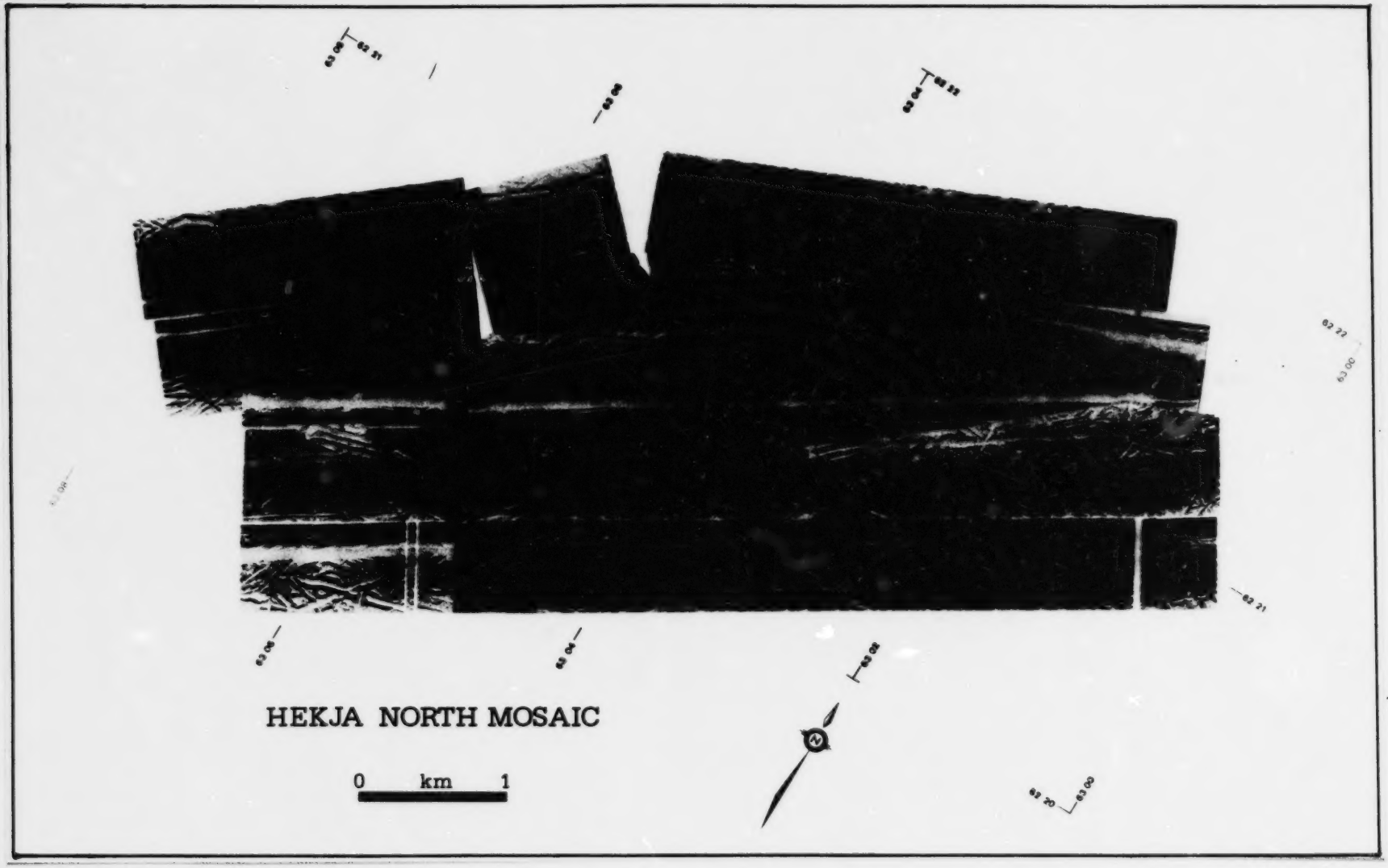


Figure 5 Hekja North mosaic constructed from BIO sidescan data.

Sediment and core samples

Ten sediment grab samples along with three gravity cores and two piston cores were collected during the survey. Sample stations are indicated in Figure 3. Stereo underwater camera photographs were collected from three sites on the shelf (Figure 3). Station coordinates for all the samples are given in Barrie 'et al.', (1982).

Iceberg Log

An iceberg log was maintained for the duration of the survey at the Hekja site, the data of which are given in Barrie, 'et. al.', (1982).

Bathymetry

Bathymetry was logged for all geophysical and multiparameter lines.

Navigation

Positions were fixed at 5 minute intervals using Bionav, an integrated system of Loran C (rho-rho) and satellite navigation, accurate to within 200 m. As a result of a slight malfunction of the navigation system on board ship, just before and during sample stations 39 and 40, only the approximate positions of these sample stations is given.

ICEBERG SCOUR STUDIES

The foci of this section of the study is to analyse the scours, both for their intrinsic morphological characteristics (i.e., scour depth, scour domains, etc.), and to determine the relative age of the individual scours or groups of scours seen on each of the two sidescan sonar mosaics.

Subsequent to the cruise, magnetic tapes of the sidescan data were replayed through a Honeywell 1856A fibre-optic visicorder and reproduced on 152 mm dry-silver paper. A distortion-corrected copy of the original data was thus produced at a reduced scale of 1:10,000. The strips of dry-silver paper with the corrected data were then assembled to form a mosaic. The mosaic was photographed at a 1:1 scale and the photographic positive used to draft a scour map (e.g. Figure 6).

Since the resolution of the BIO sidescan system is less when compared to the ORE sidescan system used by Geonautics Ltd. in their surveys at the same water depths, very few scours were identified with sufficient clarity from the October 1981 resurvey of the Hekja Wellsite area to enable cross-cutting relations to be determined. Instead, the Geonautics (1981) scour map was used to study the cross-cutting relationships for the wellsite area. The scour map (Figure 11) shows all the identifiable scours and their cross-cutting relationships.

Iceberg scour cross-cutting relationships

Absolute age dating of scours is not yet practical, however, it is possible to determine the relative age of scours one to

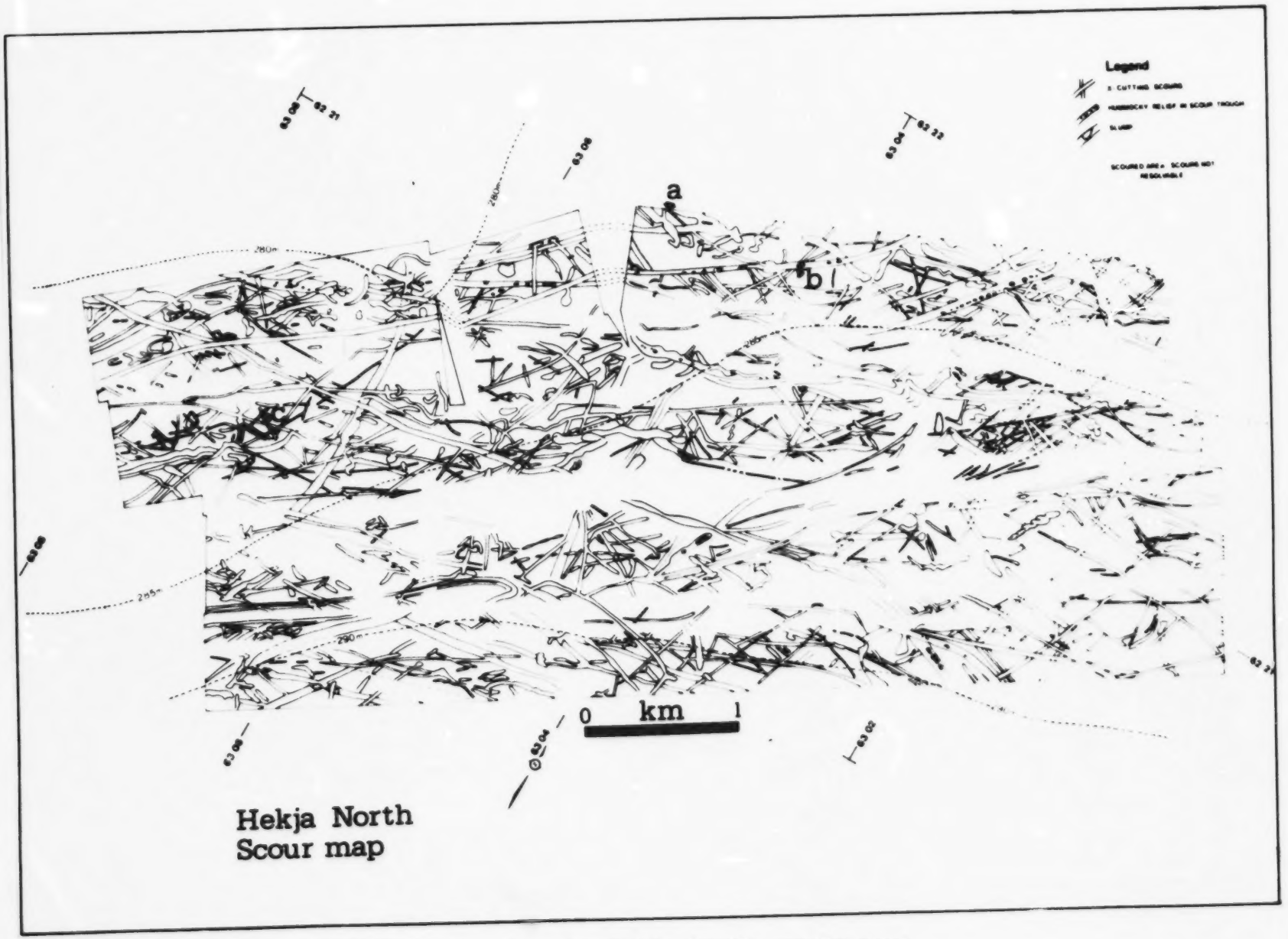


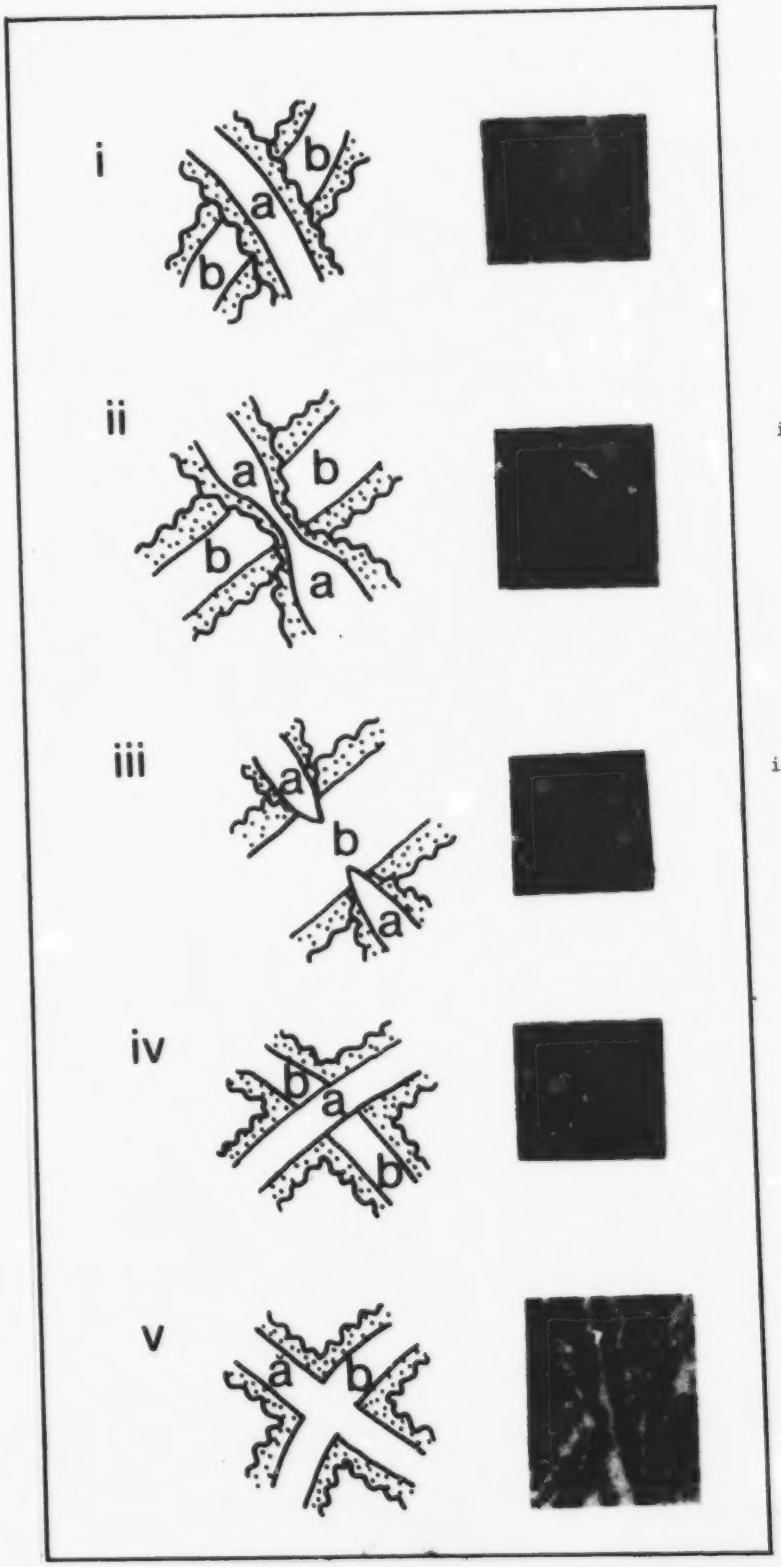
Figure 6 A scour map for the Hekja North survey area.

another using the principle of cross-cutting relationships. Essentially, this means that the oldest scours will be those that are cut by younger scours but which do not cut others, and the youngest scours will be those that cut older scours but which themselves are not cut by others.

Weber (1958) was the first to note the cross-cutting relationships of ice scours observed on aerial photographs from the Great Slave Lake region in the Northwest Territories. Here, ice floe grooves which formed during the winter by grounding wind-blown icefloes, cut across the tops of relict glacial furrows. Later Berkson and Clay (1973) in their work on iceberg scours in western Lake Superior also noted cross-cutting relationships of relict iceberg scours. They constructed a scour map from sidescan records to show scour distribution and further interpreted scour cross-cutting relationships, but did not use this as a method for determining the relative ages of the scours.

The principle of cross-cutting relationships with respect to ice scours in an open marine environment was first mentioned by Pelletier and Shearer (1972) from work in the Beaufort Sea. They observed, "numerous occurrences of cross-cutting relationships indicating that several periods of ice-scouring have occurred". Later, Hnatiuk and Brown (1977) also working in the Beaufort Sea, investigated scour marks and correlated cross-cuts with scour azimuth but found no significant relationships.

Examination of the scours in the mosaics demonstrated the need for morphological criteria to determine cross-cutting relationships; these are explained in Figure 7. In a number of



i) Scour a cuts scour b. Berms are developed across scour b.

ii) Scour a cuts scour b. Scour a is slightly deeper than scour b and thins out in the trough of scour b.

iii) Scour a cuts scour b. Scour a is shallower than scour b and is not incised into the trough of b.

iv) Ambiguous situation. Scour a is deeper than scour b but there is no berm debris to indicate which cuts which. Scour b looks older but may be younger. In this case the crosscut is recorded as unknown.

v) Scours a and b are of equal depth but there is no berm debris to indicate which cuts which. In this case the crosscut is recorded as unknown.

Figure 7 Morphological scour cross-cutting criteria. Each diagram is accompanied by a sample sidescan record to show the type of cross-cut.

instances the determination of the relative ages of two cross-cutting scours were not possible, in these instances the interpretation of the relationship on the map was left undecided (Figure 7, V).

In principle, the cross-cutting relationships of each scour were interpreted and listed as follows: for example, scour #65 has cross-cutting relationships with five other scours. These cross-cuts are referred to as either before (A) or after (B). Thus A64 means that scour #65 is before scour #64, whereas B70 means that scour #65 is after scour #70. Thus the listing for scour #65 is as follows:

#65. A64, A67, B70, B100, B85.

Scour cross-cuts that could not be interpreted as either A or B were classified as unknown (U). The unknowns, (Us), were excluded from the analysis because these could not be used to determine the relative age of a scour. A computer assigned the relative age of each scour with respect to all other scours and then sorted the scours into relative age groups.

Scour age groups

The number of scours in each age group fits an exponential distribution illustrated graphically in Figure 8, which shows that there are increasingly more scours in the older groups. An explanation for this is based on the following two assumptions; (i) that scouring began on an initially featureless surface and, (ii) that only one scour was generated at a time.

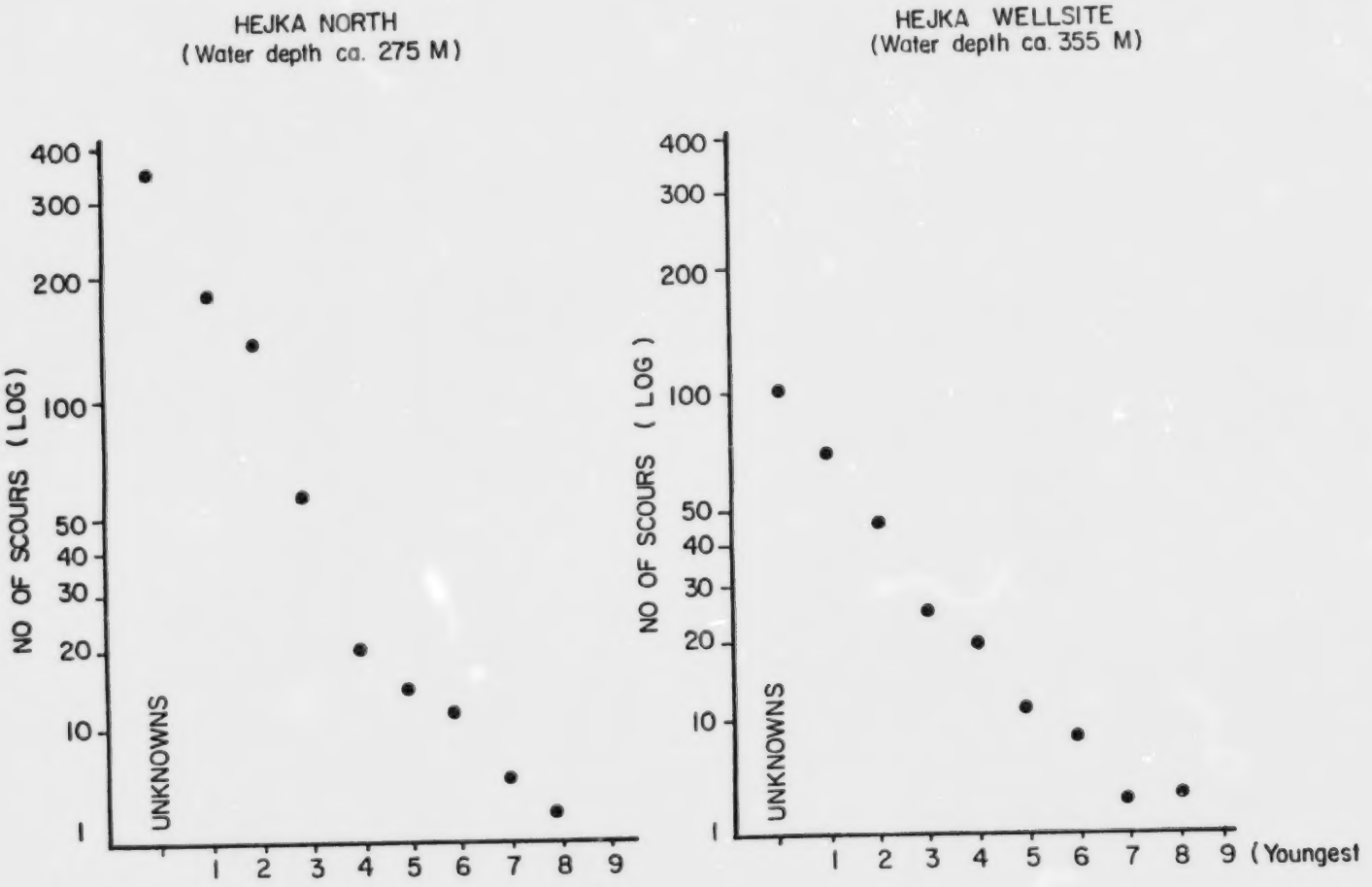


Figure 8 Graph showing exponential distribution of scours in relative age groups for the Hekja Wellsite and the Hekja North survey areas.

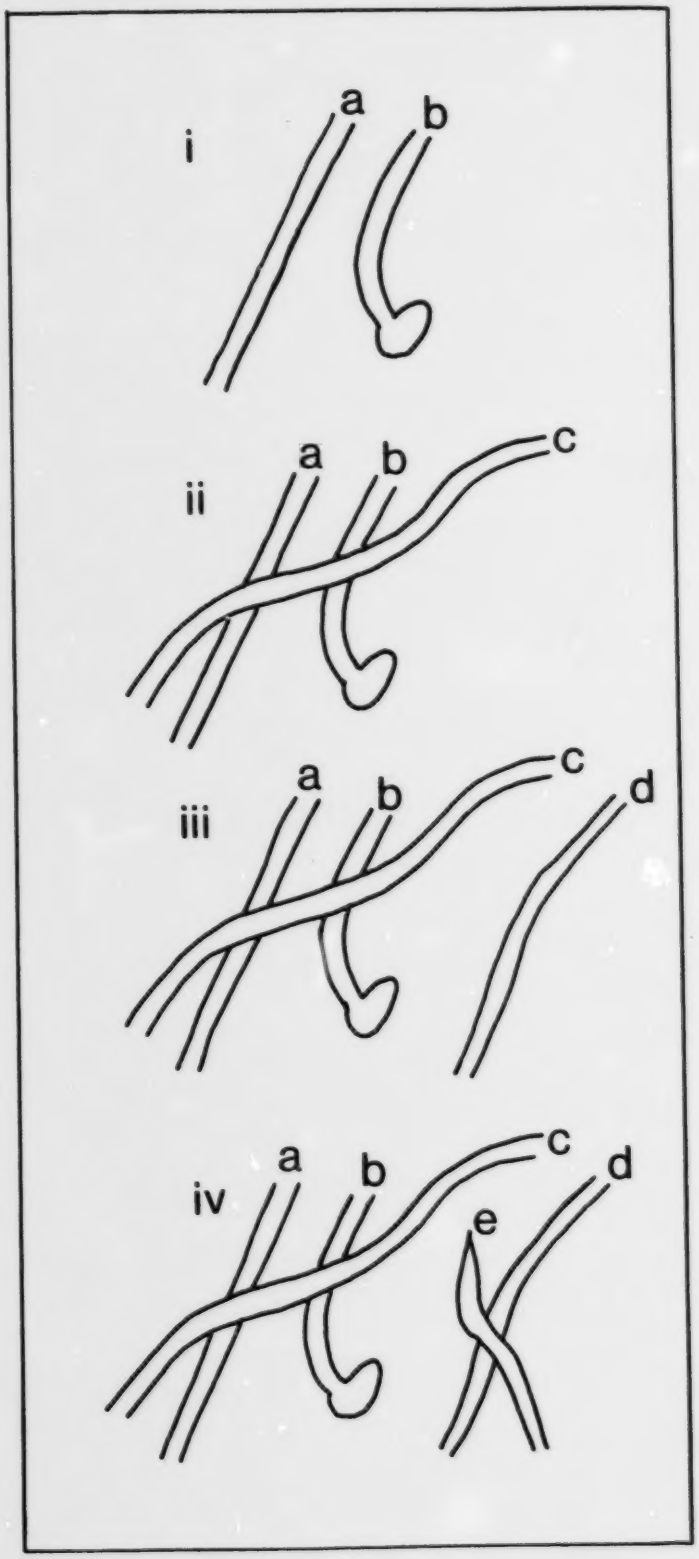
As the first few scours were generated it is assumed unlikely that they impinged on each other. Until an impingment of one scour on another occurs and a cross-cutting relationship is made, it is not possible to define the relative age of one scour with that of the other. Thus some scours which may belong to younger age groups are not recognizable as such, because of the lack of these cross-cutting relationships. Figure 9 illustrates how this can arise.

As more scours are generated there is a progressively greater probability that newer scours will impinge on one or more of the older scours. Consequently it is possible to distinguish smaller groups of younger scours with increasing accuracy.

Scour cross-cutting domains

A scour domain is an area in which all scours have known relative ages with respect to other scours in the domain. However, the ages of scours in one domain relative to scours in other domains are unknown; this is because there are no cross-cutting scours between domains. Domain boundaries on the scour maps for the Hekja North and Hekja Wellsite area are shown in Figures 10 and 11 respectively. It should be stressed that there is no correlation intended between the scour age groups and scour domains at either Hekja North or the Hekja Wellsite areas.

The linearity of scour domains on the Hekja Wellsite (Figure 11) is a function of the strongly preferred scour orientation in this area (Geonautics, 1981) possibly reflecting the prevailing currents in the area. The irregular nature of domain boundaries



i) The relative ages of scours a and b cannot be inferred because they do not cut.

ii) Scours a and b now fall into the earliest age group (group 1) because they are cut by scour c which falls into the next youngest age group (group 2).

iii) Although scour d is generated after scour c, it cannot be assigned a relative age because it has no crosscuts with a, b or c.

iv) Scours a, b and d now fall into the earliest age group (group 1) even though scour d is younger (in absolute terms) than scour c. Scours c and e fall into the next youngest group (group 2).

Figure 9 Diagram to illustrate how scours in the same relative age group are of different absolute ages.

in Hekja North probably reflects variable scour orientation, poor overlap in places and an inability to match several scours between mosaic survey lines (Figure 10). This latter point is a function of poor resolution towards the edge of the sidescan swath and cannot be compensated.

Mutually cross-cutting scours

The Hekja Wellsite area has five separate groups of mutually cross-cutting scours which are clearly identifiable and illustrated diagrammatically in Figure 12. In this case the four scours form a unique configuration which requires that they were all generated at the same time by four icebergs moving at 90° to each other such that each scour has mutual cross-cuts with its two adjacent neighbours (Figure 12). Environmental circumstances that may create this sort of situation would require unusual eddy currents! The cross-cuts in one of the five groups of scours which display mutual cross-cuts are marked by asterisks on the Hekja Wellsite scour map (Figure 11). The mutual cross-cuts may show that the original configuration of cross-cuts has been modified by later processes, possibly linked to bottom currents.

Case Studies

A - Hekja Wellsite

A total of 293 separate scours were identified from the Geonautics (1981), Hekja Wellsite data. Of these, 105 scours either had ambiguous or no cross-cutting relationships and were not included in the analysis. From the remaining 188 scours, 8

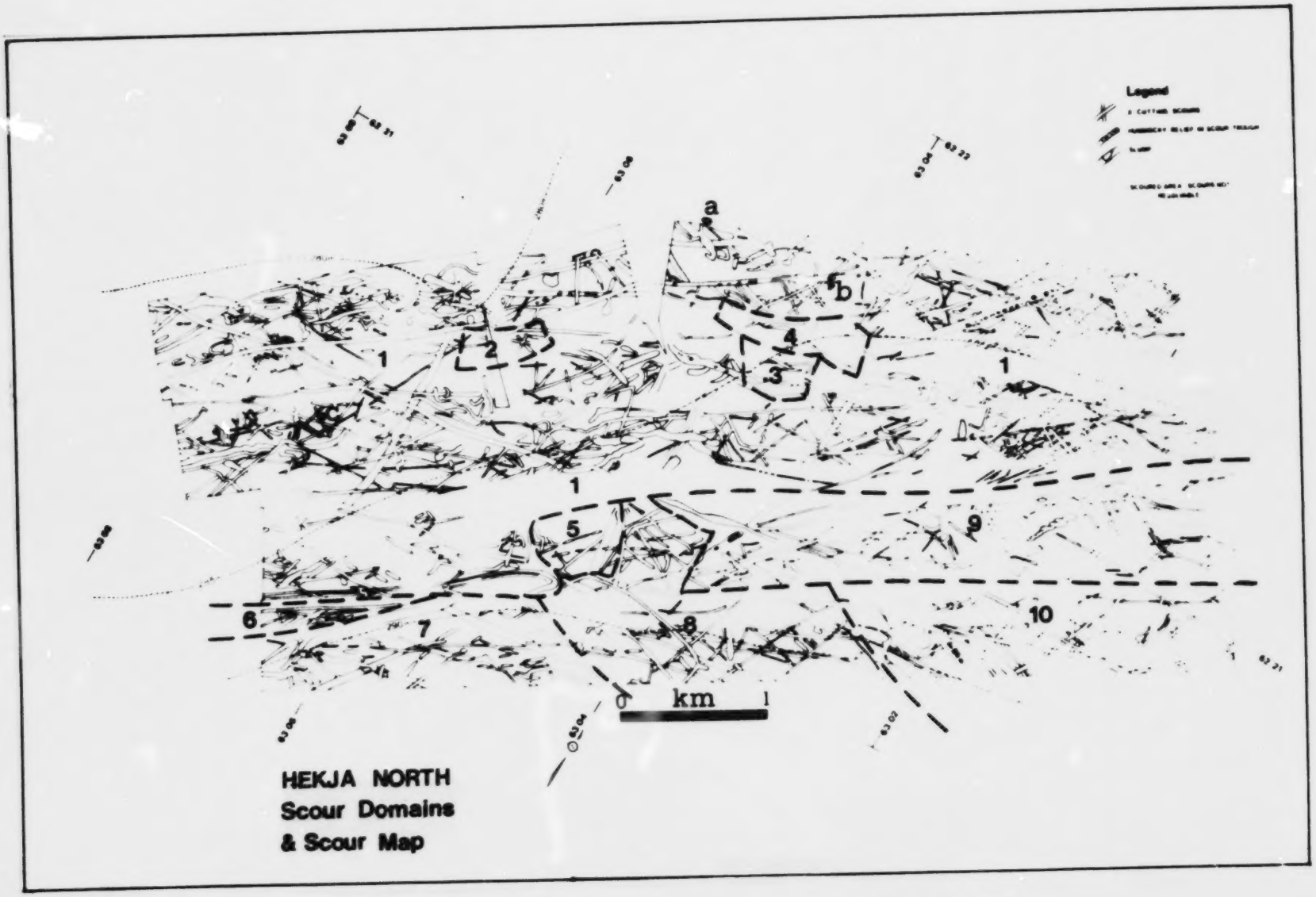


Figure 10 Hekja North scour map and scour cross-cutting domain map.

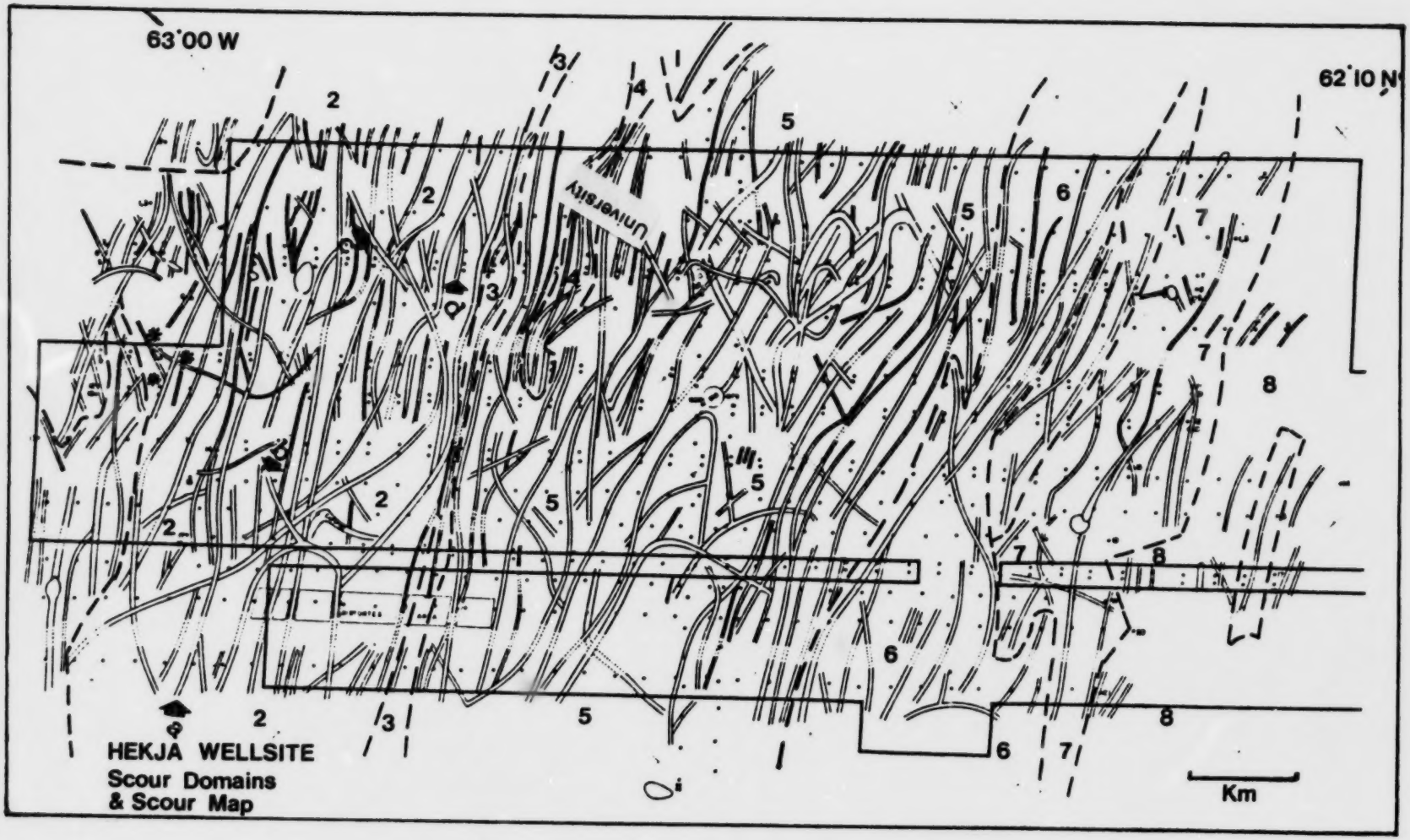


Figure 11 Hekja Wellsite scour map and scour cross-cutting domain map.

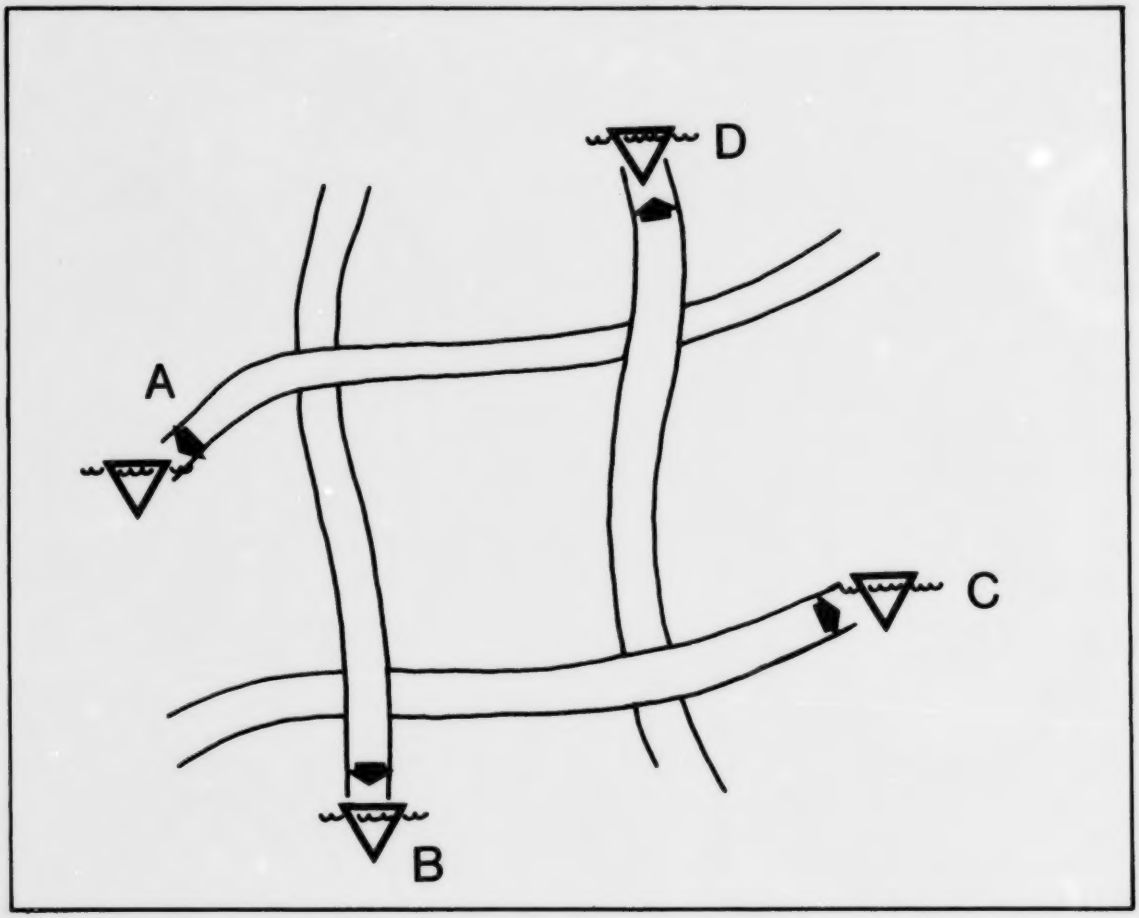


Figure 12 Mutual cross-cutting relationships of iceberg scours.

relative age scour groups and 8 scour domains were identified (Figure 11).

Scour domain 2 was chosen for analysis because it contains scours from each age group. All other domains were ignored because inter-domainal correlations based on cross-cutting criteria were not determinable. To identify the oldest scour(s) in domain 2, it is necessary to trace all cross-cuts from the youngest scour(s) (group 8) back through scours of each preceding group (from group 7 down) until the oldest scours(s) (group 1) is found.

In domain 2 there are three group 8 (youngest) scours (a, b and c in Figure 11) and all of these can be progressively linked back to a single group 1 scour (d in Figure 11). If radiometrically datable material can be cored from the troughs of scours (a) to (d) then three things could possibly be determined:

i) a minimum absolute age can be established for the oldest scour group (group 1). The age must be regarded as an average minimum value because it is likely that other scours in this age group are both younger and older than scour (d) (refer to Figure 9);

ii) the age of the youngest scour group (group 8) can be established. The age must also be regarded as an average minimum value because it is possible that young scours in other domains are both younger and older than the sampled group 8 scour,

iii) a minimum scouring rate value between the two dates can be derived for domain 2 of the Hekja Wellsite by dividing the number of scours in the domain into the time span.

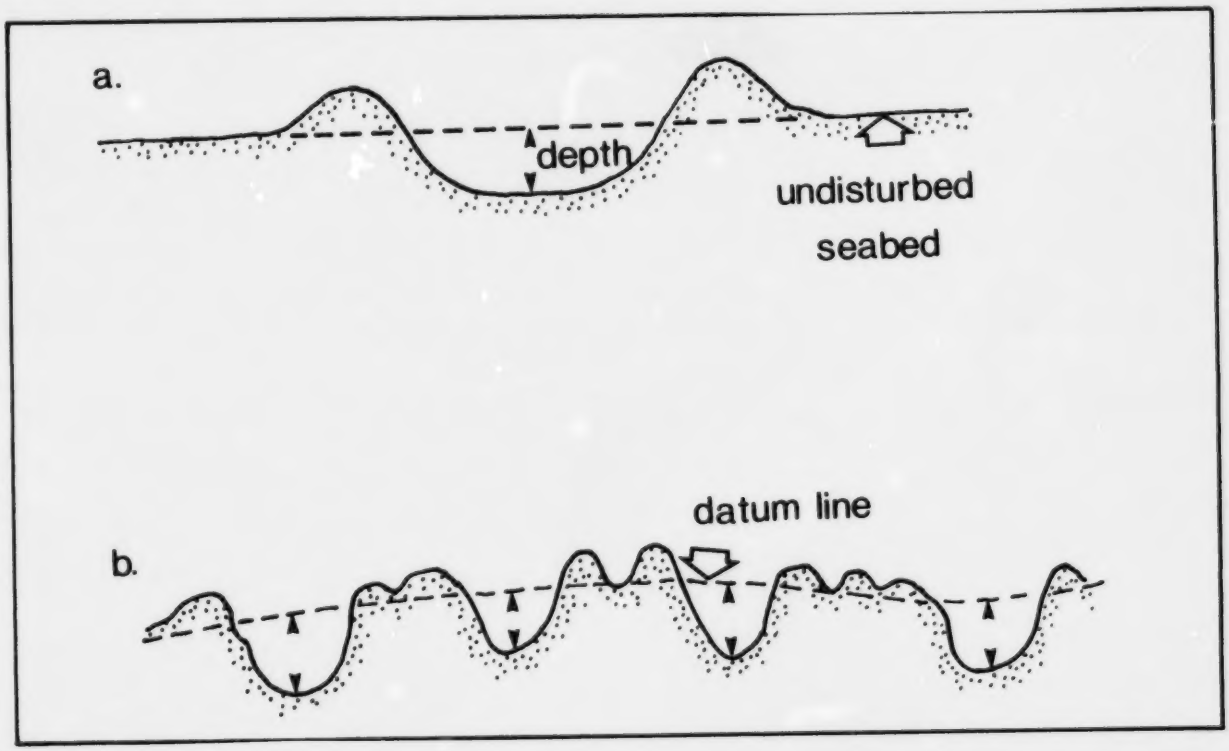


Figure 13 Diagram illustrating principle used to measure scour depth (see text for explanation).

B - Hekja North

A total of 774 separate scours were identified from the scour mosaic (Figure 5). Of these, 362 scours either had ambiguous or no cross-cutting relationships and were not included in the analysis. From the remaining 412 scours, 8 relative age scour groups and 10 scour cross-cutting domains (Figure 10) were identified. Analytical procedure was the same as for the Hekja Wellsite analysis. Scour domain 1 was chosen for this analysis because it contains scours from each age group and it also contains the most scours.

The oldest and youngest scours (group 1 and group 8) in domain 1 were selected. In domain 1 there are two group 8 (youngest) scours (a and b in Figure 10) which can be linked back to a single group 1 scour (C in Figure 10). The ages of the oldest and youngest scours can be defined and a scouring rate derived in a manner similar to that described for the Hekja Wellsite scours.

Scour Depth Analysis

Scour depths were measured directly from the Huntec DTS records as far as possible. Depths were measured from the undisturbed seafloor to the deepest part of the scour trough (Figure 13,a). In areas where the seafloor has been completely disturbed by scouring, scour depths were measured from a datum line that was assumed to approximate the original undisturbed seafloor (Figure 13,b). Scour depth statistics for the two survey sites are as follows:

A. Hekja Wellsite

A total of 164 scours were identified and measured from the Huntec DTS records of the wellsite. A summary of the scour depth data is given below:

Depth of Hekja Wellsite area = 335 - 380 m

Maximum resolvable scour depth = 3.8 m

Minimum resolvable scour depth = 0.2 m

Mean scour depth = 1.10 m

Standard deviation = 0.5

Standard error = 0.04

Range = 3.6 m

These results are considered to be more accurate than those determined by Geonautics (1981) where scour depths were measured from sonogram records which provide less precise data.

B. Hekja North

A total of 131 scours were identified and measured from the Huntec DTS records of the Hekja North survey site. A summary of the scour depth data is given below:

Depth of Hekja North area = 280 - 290 m

Maximum resolvable scour depth = 4.4 m

Minimum resolvable scour depth = 0.4 m

Mean scour depth = 1.27 m

Standard deviation = 0.75

Standard error = 0.07

Range = 4.0 m

The mean scour depth is slightly greater in the Hekja North area (mean depth 1.27 m) than it is in the Hekja Wellsite area (mean depth 1.10 m). This is in contrast to observations in scoured areas of the Beaufort Sea (Lewis, 1978) and Saglek Bank and Labrador Shelf (Barrie, 1980) where it has been shown that scour depth increases with increasing water because large icebergs, which are restricted to deep water, have the potential to scour deeper troughs than smaller icebergs in shallower water.

Increasing scour depth with decreasing water depth in the Hekja area may be explained as functions of:

i) probable changes in the geotechnical properties of the scoured sediments and,

ii) preferential infilling of originally deeper scours in deeper water.

iii) In addition, subseabed bed morphology (i.e., depth of unconformity) and the prevailing current regime are factors which must also be given serious consideration.

A change in geotechnical properties of the deeper water surficial sediments is suggested by the decrease in the surficial sand content with increasing water depth (from a maximum value of 85% at approximately 100 m to a minimum value of 46% at about 400 m, Table 1).

The subdued relief of scours and the presence of megaripples (seen clearly in the sonar records, and only just discernible in the mosaics) in the troughs of scours in the Hekja Wellsite area (Figure 4) suggest that preferential infilling has occurred. This contrasts with scours in the Hekja North area which have

sharper relief (Figure 5) and are slightly deeper. The deeper scours of Hekja North suggest that infilling and degradation has not occurred or has occurred to a much lesser extent. Preliminary variability analysis of scour depth with respect to water depth along survey lines A, B and C (Figure 3) substantiate the observation that deeper scours occur in shallower water. However, preliminary curves of scour depth versus water depth show a non-linear correlation. It is possible that the non-linearity may be a function of preferential infilling of scours and of variations in the geotechnical properties of the seabed at certain depths.

TABLE I

TEXTURAL ANALYSIS OF SEDIMENT SAMPLES FROM THE SOUTHEAST BAFFIN SHELF (IN %)

St. No.	Water Depth (m)	Gravel	Sand	Silt	Clay
38	137	32.96	67.07	-	-
39	115	14.72	85.28	-	-
40B	82	46.27	53.73	-	-
42	133	35.07	64.93	-	-
43B	155	13.22	86.78	-	-
44A	365	62.07	32.33	3.97	1.63
47B	397	49.89	46.11	2.41	1.58
49	256	100	-	-	-
50	265	6.97	54.65	35.90	2.49
Core barrel scrap samples - Core penetration 2.8 m					
44B (Barrel top)	365	39.32	32.31	22.90	5.48
44C (Barrel bottom)	365	0.0	37.68	31.37	30.94

GEOPHYSICAL STUDIES

Geophysical programs to study the subsurface geology of the southern Baffin Island Continental Shelf have been in progress since 1971 (eg., Grant, 1975; Falconer, 1977; MacLean 1978, 1981; MacLean 'et al.', 1977a, 1977b; MacLean and Falconer, 1979), and were principally undertaken between Cape Dyer and Resolution Island with a few lines farther south. These studies were designed to determine the regional marine geology for this remote northeastern offshore area of Canada.

In the present study, information derived from the seismic data about the varying thickness of the sedimentary overburden at the Hekja wellsite and adjacent areas was necessary to effect a successful coring program. In addition, the seismic lines were run along possible pipeline routes, to determine the existence of any geological or other hazards which might affect their safe emplacement and maintenance.

Geophysical data of the surficial and subsurface geology were obtained using a Huntec deep-tow system and a 655 cu. cm airgun system respectively. These systems complement one another in that the airgun seismic system provides data on the nature and structural conditions of the bedrock and the Huntec system provides data on thickness of the overburden sediment, mantling the bedrock. The airgun which is a compressed air, acoustic source is towed behind the vessel near the sea surface, opposite the "eel" containing the hydrophones; it collects the reflected acoustic pulses from the seabed and subsurface reflectors down to depths exceeding 400 m.

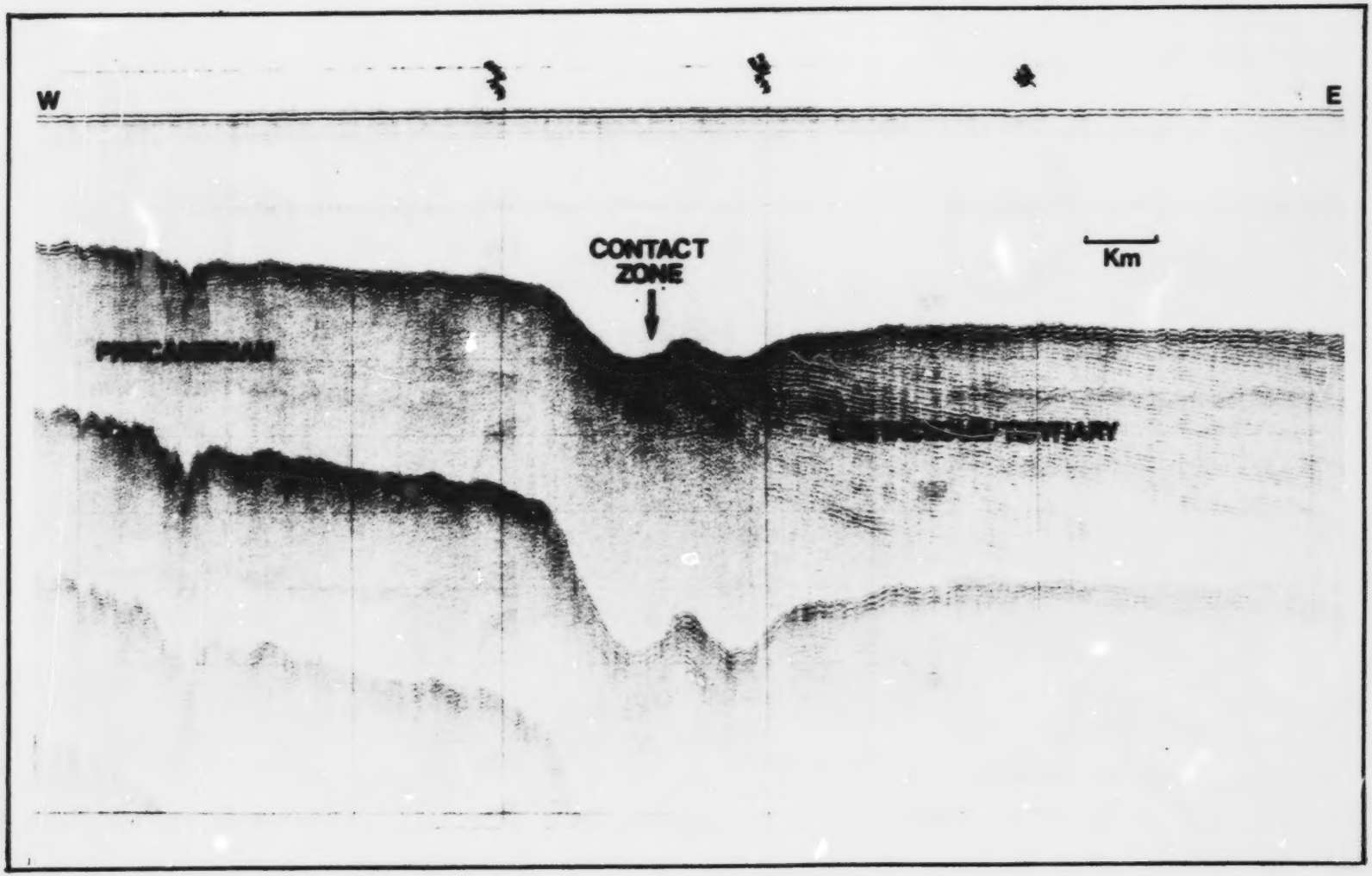


Figure 14 Airgun seismic profile along survey line A, showing contact zone between the Precambrian and Cretaceous-Tertiary strata.

The Huntec fish employs a "boomer" source which is capable of producing energy in band cycles of between 800 Hz and 10 kHz in a narrow beam which can penetrate an acoustically "hard" seabed to depths exceeding 33 m (Hutchins, 'et al.', 1976). Airgun and Huntec data were recorded simultaneously on EPC recorders and on 1/4" magnetic tape. Both systems automatically marked the time intervals, every five minutes on the Huntec record and every half hour on the airgun record.

Airgun seismics

The profile of seismic line A (Figure 3) commenced at 62° 24.07'N, 63° 39.0'W, and was run southeastward to the Hekja wellsite. The initial section of the profile indicated a bedrock basement (Precambrian in age) with a variable distribution of overburden sediment and occasional bedrock exposures. The seabed sloped gently in a southeasterly direction and showed very few obvious signs of iceberg scouring. At about 62° 22.51'N, 62° 29.54'W, the contact between the Cretaceous-Tertiary bedrock to the east and the Precambrian bedrock to the west was recognized on the profile. Figure 14 illustrates a truncated erosional feature with possible sediment accumulations on either side in the adjacent depressions. The Cretaceous-Tertiary beds dip eastward and the overburden gradually thickens towards the Hekja Wellsite. From about the 225 - 250 m depth interval, the seabed surface is heavily scoured all the way to the wellsite.

The profile of seismic line B (Figure 3), commences 62° 30.89'N, 63° 09.47'W at a water depth of 215 m and is terminated

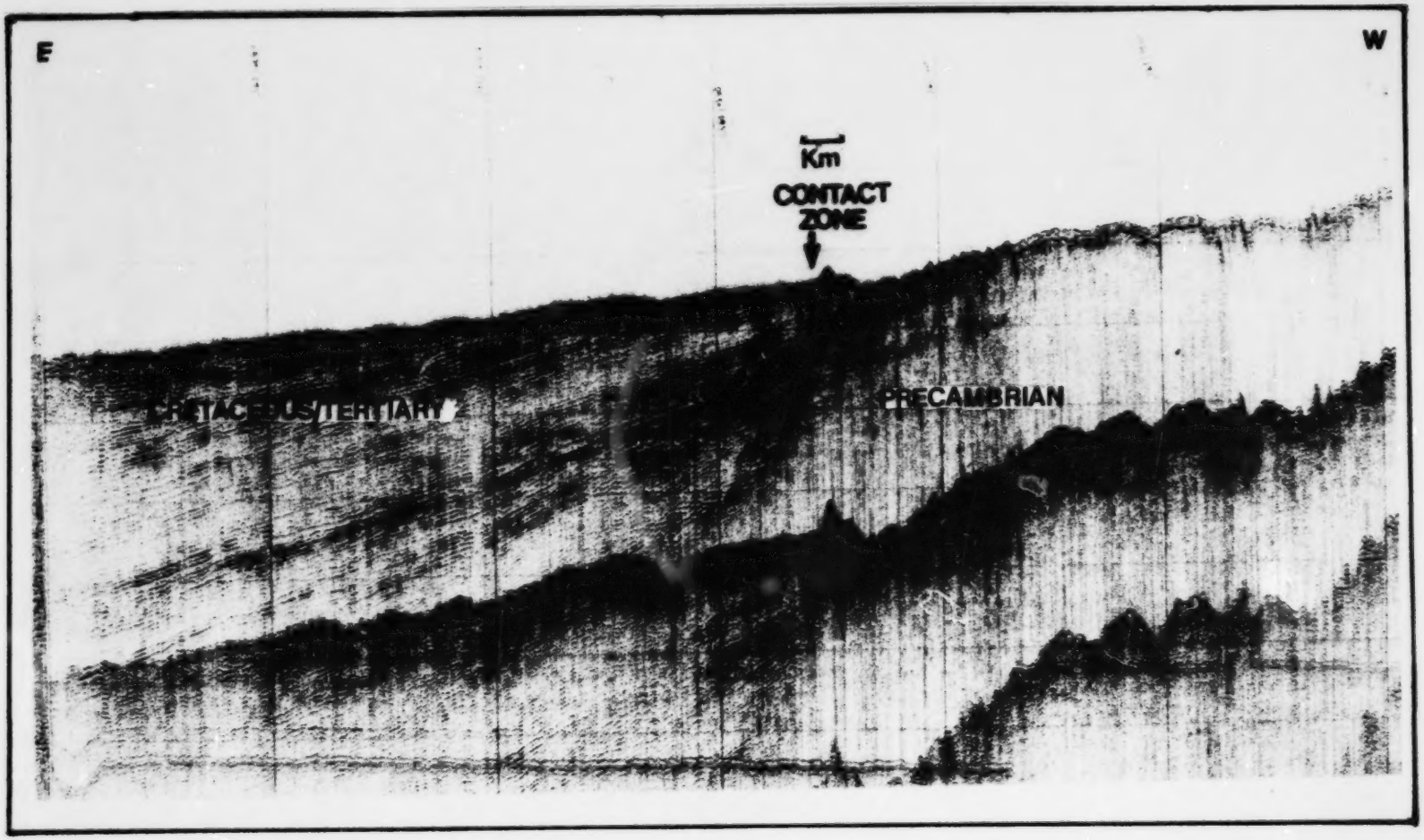


Figure 15 Airgun seismic profile along survey line C, showing contact zone between the Precambrian and Cretaceous-Tertiary strata. Also seen over the contact zone is the feature interpreted to be a mud volcano (Woodworth-Lynas, 1983a).

at the commencement of the Hekja North sidescan survey at a water depth of about 280 m. The profile which was run almost normal to the dip of the Cretaceous-Tertiary bedrock indicates a very heavily scoured seabed with a variable sediment cover.

The seismic profile line C (Figure 3), commences at 62° 22.97'N, 63° 05.97'W and terminates close to station No. 43. The seismic information gathered from this line corresponds to that collected on line A. At the junction with D just east of the Cretaceous-Tertiary/Precambrian contact, a feature not dissimilar to that seen on profile line A is clearly evident (Figure 15). Here, the contact which is less ambiguous, is immediately west of the feature and Woodworth-Lynas (1983b), interprets the feature as a mud volcano.

The seismic profile line D which commences at 62° 27.90'N and 63° 45.80'W and traverses along the southeast coast of Baffin Island is entirely over a Precambrian basement bedrock which appears to be truncated by relatively sharp transverse gullies a few of which are about 50 m deep (Figure 16). However, bathymetric analysis of data collected in this area by the Canadian Hydrographic Survey and Canterra Energy Ltd. (J. Warren, Canadian Hydrographic Survey, pers. comm. 1984) suggest that these indentations are in fact, shallow elongated topographic hollows which have a maximum diameter of about 2 km. Seismic line D then rejoins the BIO multiparameter line 5 at 62° 01.40'N and 64° 24.98'W at a water depth of 280 m and at 62° 00.01'N and 64° 02.41'W the Precambrian/Cretaceous-Tertiary contact is seen again (Figure 17). At this point the seabed slopes sharply

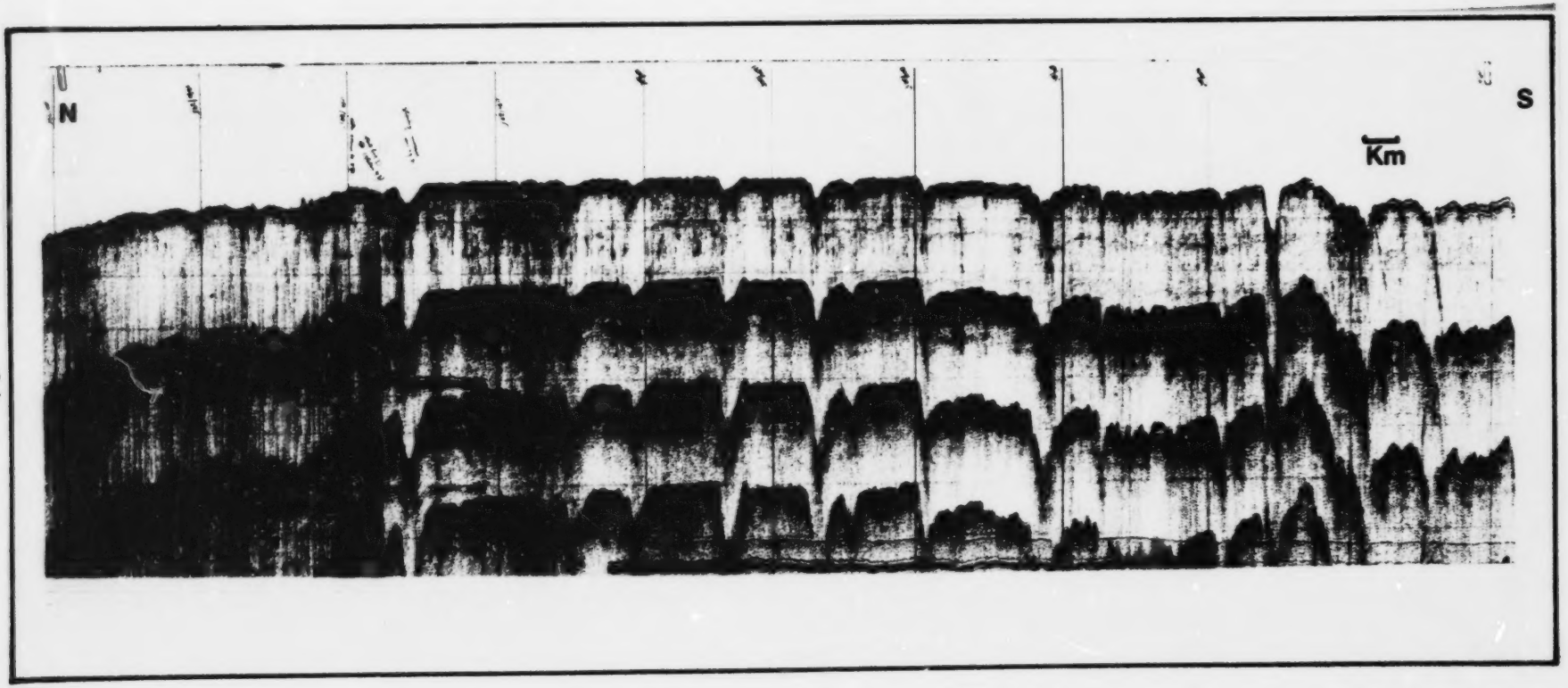


Figure 16 Airgun seismic profile along line D, illustrating indentation features seen on the Precambrian bedrock. Recent bathymetric studies suggest these may be localized hollows (J. Warren, Pers. com., 1984).

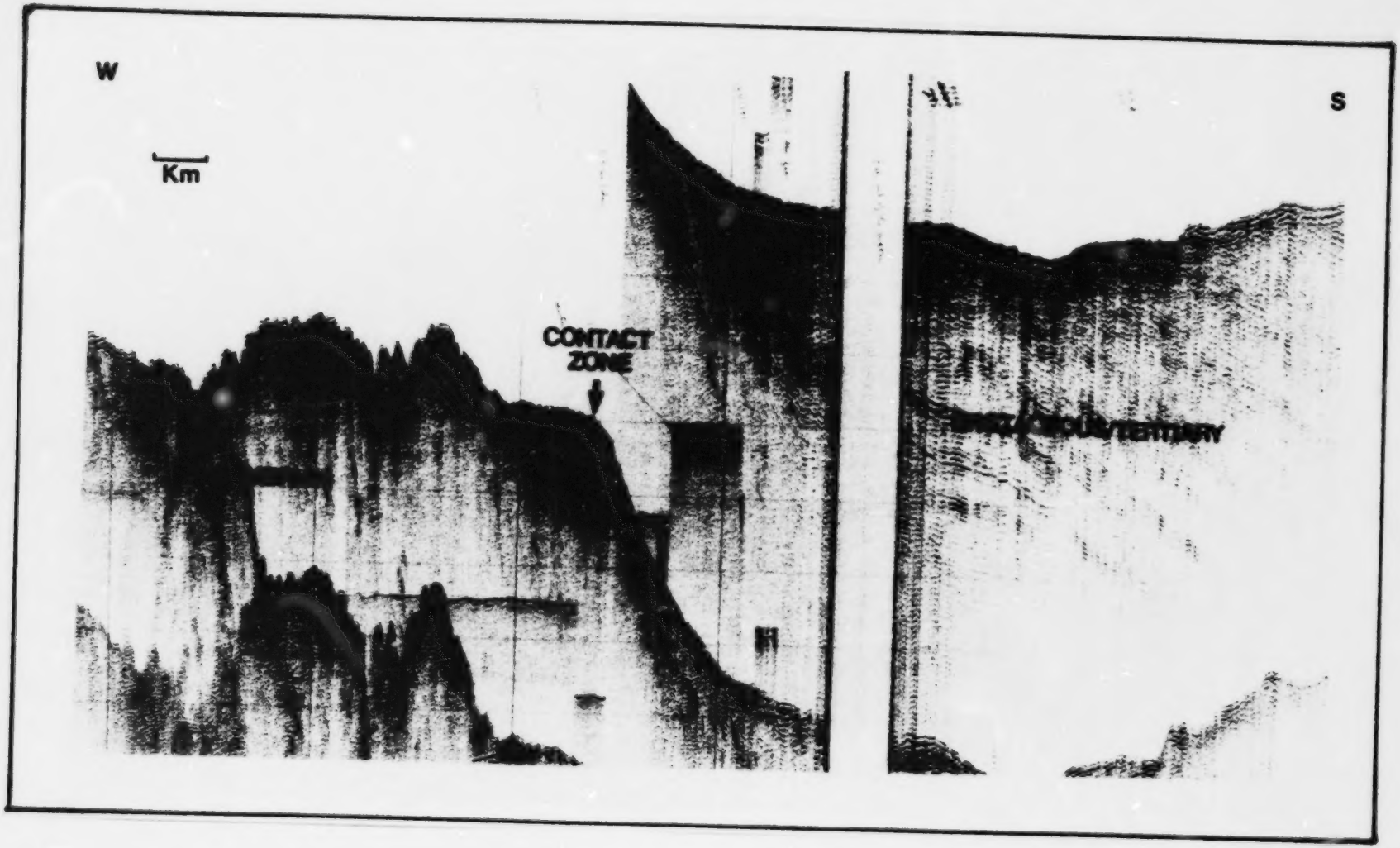


Figure 17 Airgun seismic profile along survey line 5.

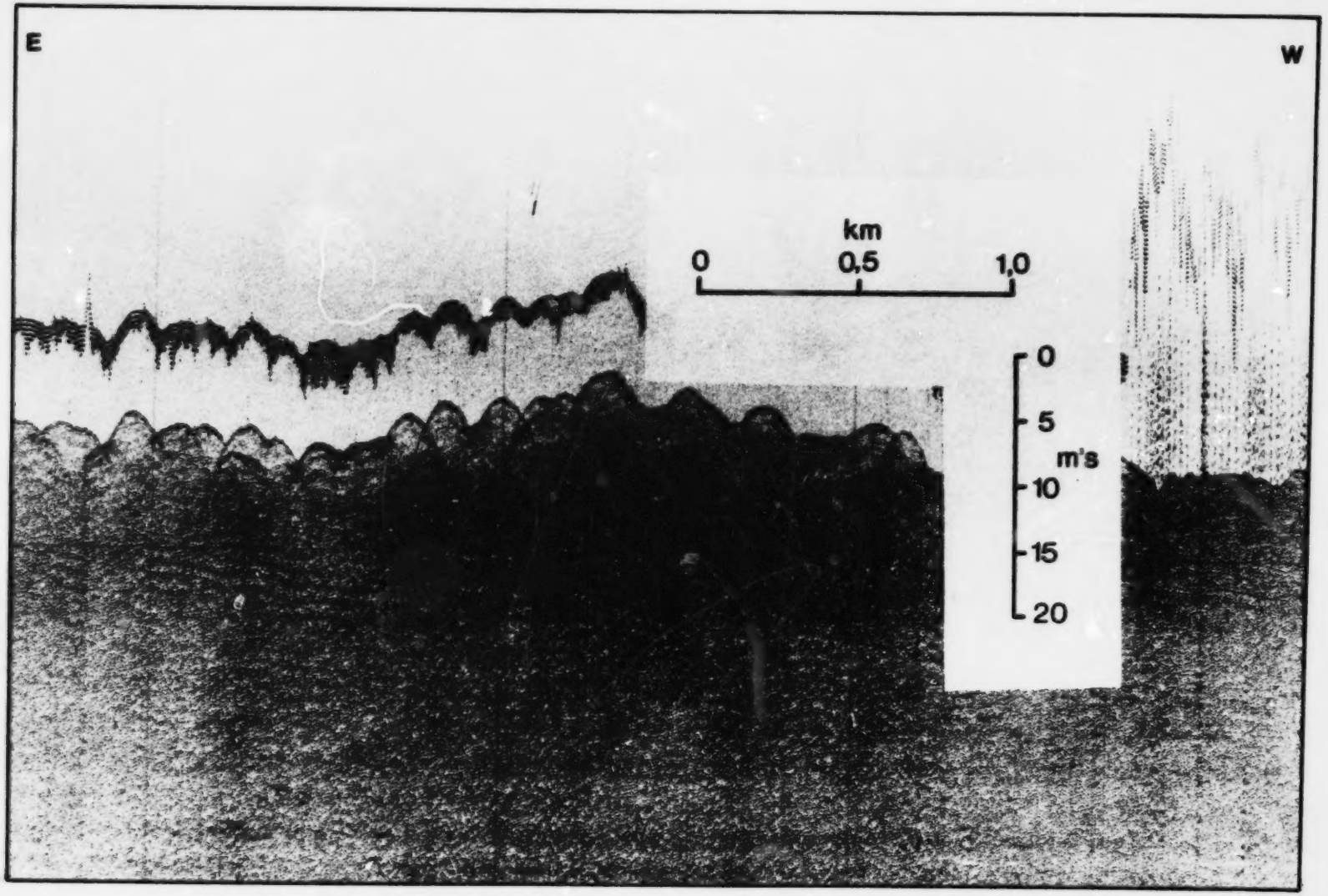


Figure 18 Huntec DTS profile showing a thoroughly scoured seabed.

eastward and a trough-like feature which is about 40 km long, is evident. Thereafter the seabed very gently slopes towards the continental shelf margin; the thickness of the sediment overburden increases with water depth.

Huntec DTS seismics

Although the Huntec acoustic penetration for this area was poor, it clearly profiled the thoroughly scoured seabed from a water depth of about 225m to the wellsite. The poor penetration is primarily attributed to the well compacted sediments found in this area and to a malfunction of the Huntec deep tow system. However, a gently undulose buried unconformity can be discerned in places and beneath this unconformity, southeasterly dipping strata (of probable Tertiary age) are identifiable (Figure 18). The depth of this unconformity below the seabed in the survey area varies from a minimum of about 2 m to over 7 m (Figure 18).

The depth of burial of the unconformity exceeds 50 m at the shelf edge and the angular nature of the unconformity can be clearly seen on the airgun record (Figure 19). In the Hekja North survey the unconformity is sometimes exposed (Figure 18) and it is likely that iceberg keels which have scoured the seabed have not penetrated through the unconformable surface. If this is indeed the case, then some of the iceberg scour depth data cannot be compared to areas where the sediment overburden is thicker and penetration of an iceberg keel is true.

In the Hekja North area, several scours exhibit hummocky relief in the troughs (Figures 5 and 6). These may be scours

Figure 19 Huntec DTS profile showing depth of unconformity and sediment overburden at the edge of the continental shelf.

that have penetrated through the surficial sediment to the Tertiary (?) bedrock unconformity. The hummocky relief may be caused by large blocks of semi-consolidated (Tertiary?) sediments that have been dislodged during the scouring process. The blocks are large and range in size from about 5 - 30 m. It is possible that scours in the wellsite area also penetrate to the unconformity but because they have been partially filled by sediment, the hummocky relief indicative of this is not apparent.

The general surficial relief of the Southeast Baffin Island continental shelf, is smooth varying between 1 to 7 m (Praeg, 1982) and this is supported by the geophysical data collected in this study.

SEDIMENTOLOGY

The shelf off southern Baffin island is blanketed by surficial deposits which are considered to be mainly drift material dating from the Quaternary glaciation and probably derived through reworking (McMillan, 1973; Grant, 1975). However, Baker and Friedman, (1973) and Osterman (1982) share the opinion that the sediments appear to be deposited predominantly by iceberg rafting. MacLean and Falconer (1977a) suggest the further possibility that an ice shelf could have been the dominant source for the sediment. These deposits overlie a predominantly smooth erosional surface throughout much of this area. The thickest accumulations of surficial deposits lie opposite the mouths of Hudson Strait, Frobisher Bay and Cumberland Sound. Off Hudson Strait there is a deep erosion of the coastal plain strata and subsequent infilling by at least two major depositional units, presumably related to the Quaternary glacial period (Grant, 'op. cit.') or even possibly to the late Tertiary. The zero-edge of unconsolidated deposits (sediment overburden) off Hudson Strait and northeast from Frobisher Bay lies on basement rocks just west of the coastal plain wedge, nevertheless grab samples in these areas commonly retrieve gravel, indicating localized coarse lag cover (MacLean, pers. comm., 1983).

Along the southeast coast of Baffin Island, two dominant sedimentary facies persist: (1) an inner shelf type with heavy mineral assemblages typical of those derived from the Precambrian metamorphic and igneous rocks on shore and (2) an outer shelf

assemblage of clay/silt matrix with carbonate pebbles. These carbonate pebbles have probably been derived from more than one source with components deposited by icebergs calved from islands to the north which contain limestone and dolomite ('vide' Marlowe, 1968 and Kranck, 1964) and from the Ordovician carbonate bedrock underlying parts of the shelf (McMillan, 1973).

Ice rafting appears to be the dominant contributor of fresh sediment into the area and most of the sediment is reworked. However, Trask (1932) has reported the occurrence of frosted grains, which make up a not insignificant percentage of the sediments which are distributed from the Davis Strait to Newfoundland. Frosted sand grains prevail in the Ungava Bay area and are probably reworked Pleistocene aeolian sand dunes that are now submerged (Johnson, 1967). The present current regime is the most probable cause for their redistribution along the Labrador shelf.

Sediment textural distribution

The objective of the sediment grab program was to retrieve samples from topographic hollows and highs at a variety of water depths. This was done to show the regional variation or extent of uniformity of sedimentary distributional patterns.

The sampling area and the 10 sites are shown in Figure 3. Water depth at the sites varied between 82 m and 400 m. All the samples were collected with a Van veen grab sampler. Statistical grainsize and textural analysis of all the samples was conducted in the laboratory using the settling tube method. The raw data

for each sample were processed on an Apple IIe computer to give the weight percent in each phi unit and the standard statistical parameters. The silt and clay fractions were analysed using the standard pipette method (Folk, 1980). Table 1 shows the textural analysis of the samples and Table 2 shows the derived statistical parameters.

TABLE 2

GRAIN SIZE STATISTICAL PARAMETERS OF SEDIMENT SAMPLES FROM THE SOUTHEAST BAFFIN ISLAND SHELF (by the Method of Moments)

St. No.	Depth (m)	M_2	I	Sk_I	K_G
38	137	0.410	0.761	-1.164	4.329
39	115	0.459	1.071	-0.688	2.908
40B	82	0.465	0.679	-0.627	5.664
42	133	0.522	0.731	-0.368	4.979
43B	155	0.580	0.750	+0.647	4.855
44A	365	0.267	1.789	+2.171	7.294
47B	397	0.312	1.598	+1.755	7.910
49	256	-	-	-	-
50	265	0.101	2.539	+0.498	1.975
Core barrel scrap samples - Core penetration 2.8 m					
44B (Barrel top)	365	0.127	2.874	+0.800	2.040
44C (Barrel bottom)	365	0.046	2.945	+0.013	1.381

The classification of Folk (1980) is used in describing the textural distribution of the sediments. Using this classification the areal distribution of the textural units were mapped (Figure 20).

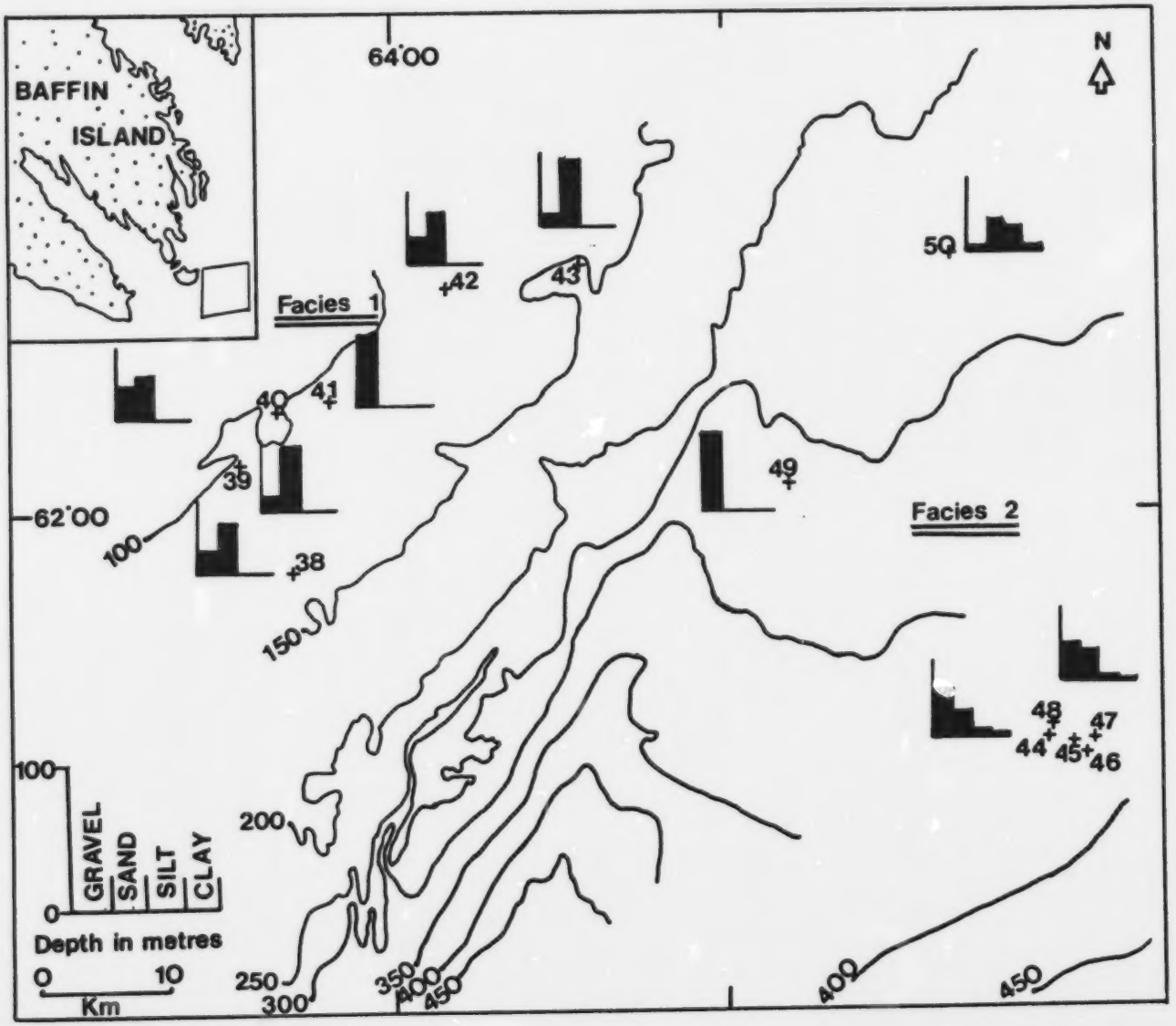


Figure 20 Sediment textural distribution of grab samples collected from the southeast Baffin Island Shelf.

The number of samples collected and analysed are quantitatively insufficient to define significantly the various sediment facies and their areal limits on the surveyed southeast Baffin Island continental shelf. Nevertheless, when these samples are analysed in conjunction with the underwater photographs of the seabed, two distinctive but gross sedimentary facies are evident (each camera transect was of about 100 m). Each facies show distinctly different bottom sediment characteristics and although the sedimentary facies described here are based on different criteria to that described by Kranck (1964) and Marlowe (1968), they do resemble the distribution patterns suggested by these authors.

Facies 1 occupies the northwestern part of the survey area, in waters shallower than 150 m (Figure 20). Texturally this area is either dominated by sand or gravel with negligible amounts of silt and clay. A 100 m long underwater camera transect of the seabed of about 100 m cleary shows an area dominated by pebbles, rocks and broken shell fragments. The epifauna consists of echinoderms and worm tubes (Figure 21a). Bioturbating infauna are not evident. While it is difficult to determine if the underlying bedrock outcrops in this area, a few of the rocks seen in Figure 21a, may be evidence of this.

Facies 2 occupies the southeastern part of the survey in water deeper than 225 m down to the Hekja survey area at between 350 m and 400 m. Texturally, this area is highly variable (Figure 20), from areas where gravel ranges from a few percent to almost 100%, to areas with an almost even 50:50 mix of sand and

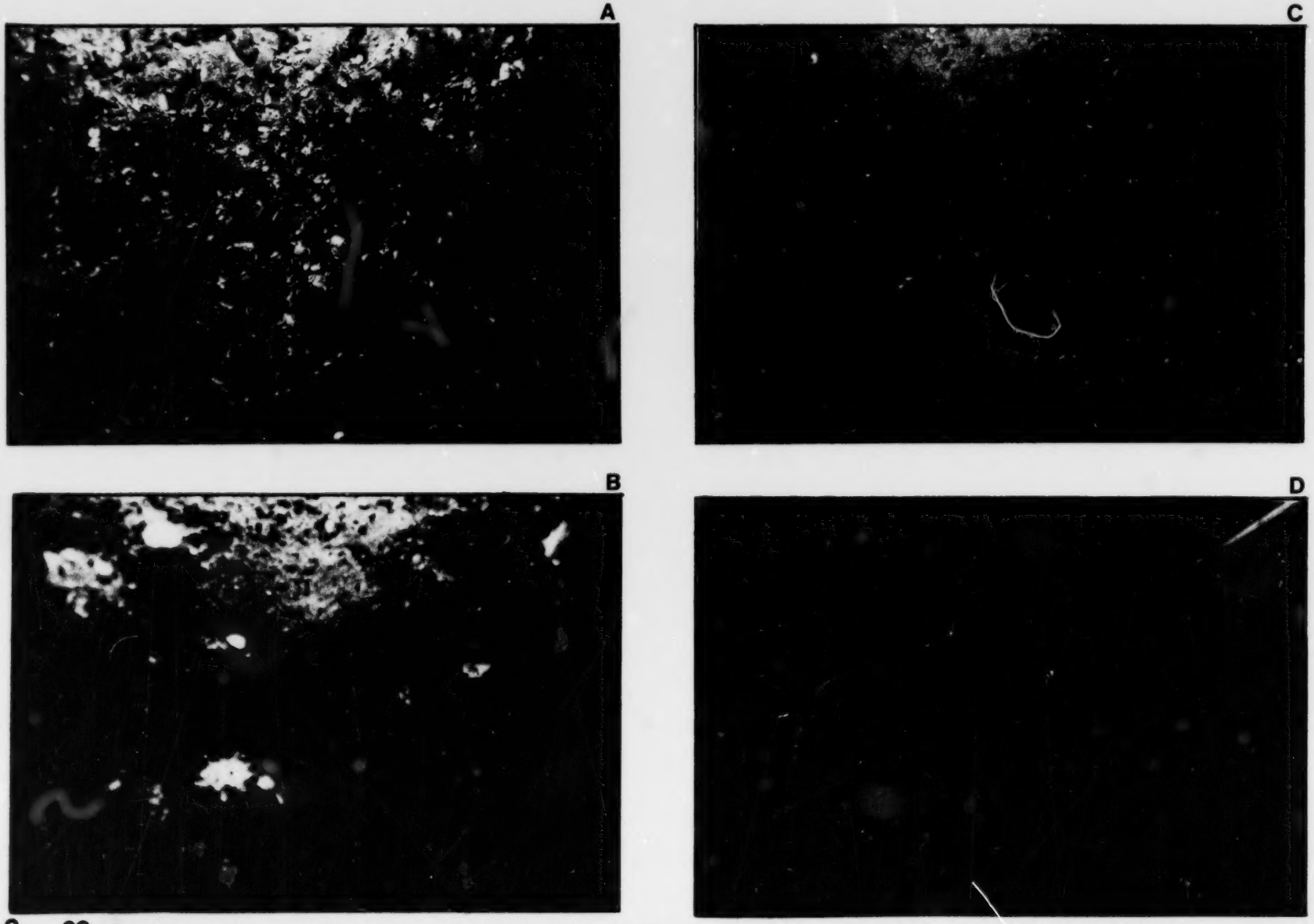


Figure 21 Underwater photographs from the southeast Baffin Island Shelf (see text for explanation).

gravel. At the shallower sites, silt and clay were present in negligible amounts, but in the deeper waters they constitute up to 38% of the whole sample (Table 1). Two underwater camera transects of the seabed were made at the Hekja Wellsite at depths between 350 and 375 m. The photographs from the two areas (Figures 21b,c,d) show an area covered by sand and occasional pavements of pebbles (Figure 21d). Randomly distributed across the seabed are small (ca. 5 cm) to large (30-60 cm) rock clasts. Some of these clasts are partially buried by the sediment whilst others are not. The most probable origin for these clasts is from ice and iceberg rafting. Most rock clasts are partially encrusted by algae (and hence indicative of their prolonged stay on the seabed) and the only other indicator of epifauna are worm tracks (Figure 21b). Outcropping of the bedrock is not apparent in any of the photographs. The transect also shows some poorly to well developed symmetrical sand ripples of small amplitude (Figure 21c).

Grain size distribution

Sediments from the shallower sites (primarily facies 1) have a bimodal sand distribution which is not so clearly evident in the deeper sites at approximately 150 m. This suggests two sources for the sediments in the area: 1) the break down end-products of biogenic carbonate material and 2) non-carbonate terrigenous derived sediment. In contrast to this, only a few sites deeper than 150 m have a bimodal sediment distribution with each modal point being in the sand and silt fraction respectively. Here the bimodality may reflect either different

suites of minerals, rather than a biogenic/non-biogenic mix, or perhaps different depositional mechanisms. A mineralogical analysis would be necessary before one or the other view can be substantiated.

The standard deviation (σ) is a measure of the sorting which reflects the consistency in the energy level around the sediment. The standard deviation varies from 0.761 (moderately sorted) in the shallower water to 2.539 (poorly sorted) just north of the survey area. This trend is well marked (Table 2) and probably reflects the better sorting efficiency in the shallow shelf area by the hydrodynamic regime. Notwithstanding the strong tidal currents in the Hekja area, they are perhaps not sufficient to sort the sediments efficiently. Also a slow but steady input of sediment from icebergs probably further inhibits proper sorting.

The skewness (Sk_I) denotes the symmetry of the grain size frequency distribution. Symmetrical curves possess '0' value, those with excess fine material show a positive value, and those with excess coarse material have a negative value. Table 2 shows the gradual positive increase in the value of Sk_I in the downslope direction. This suggests a relative increase of the fine-grained fraction of the surface sediment samples in the downslope direction probably as a result of downslope decrease in the transporting capacity. The only surface sediment samples showing a negative value of Sk_I are from the sites shallower than about 100 m.

Sediment core analysis

Two cores collected from the Hekja Wellsite vicinity (Figure 3) were examined in this analysis. Prior to splitting the cores for sedimentological analysis, they were x-rayed in the laboratory. X-ray analysis of cores is useful because they highlight internal structures, such as laminations, marked sediment gradations and mixing of sediments due to bioturation. These and other information from the x-ray analysis aid in the determination of the depositional and temporal history of the core and the area in general.

Cores #44 and #45 were collected immediately southwest of the Hekja Wellsite (Figure 3). Gravel is randomly scattered throughout both the cores, which are dominated by fine sand and silt (Figure 22). Two pebbles, each almost equivalent to the diameter of the plastic core barrel were found in each core. The gravel consists predominantly of rock fragments; shell fragments are not common. Deposition appears to have been continuous in both areas from where the cores were taken, with no significant disruption of deposition. Bioturbation is not noticeable which perhaps indicates that the area is unsuitable for benthic fauna and may reflect the harsh physical environment. Laminations occur in the top 60 cm in core #44 and in the first few centimetres of core #45.

After the x-rays were taken, the cores were split and a visual analysis of the sediment was undertaken. In addition, when subsamples of the cores were washed and sieved for their

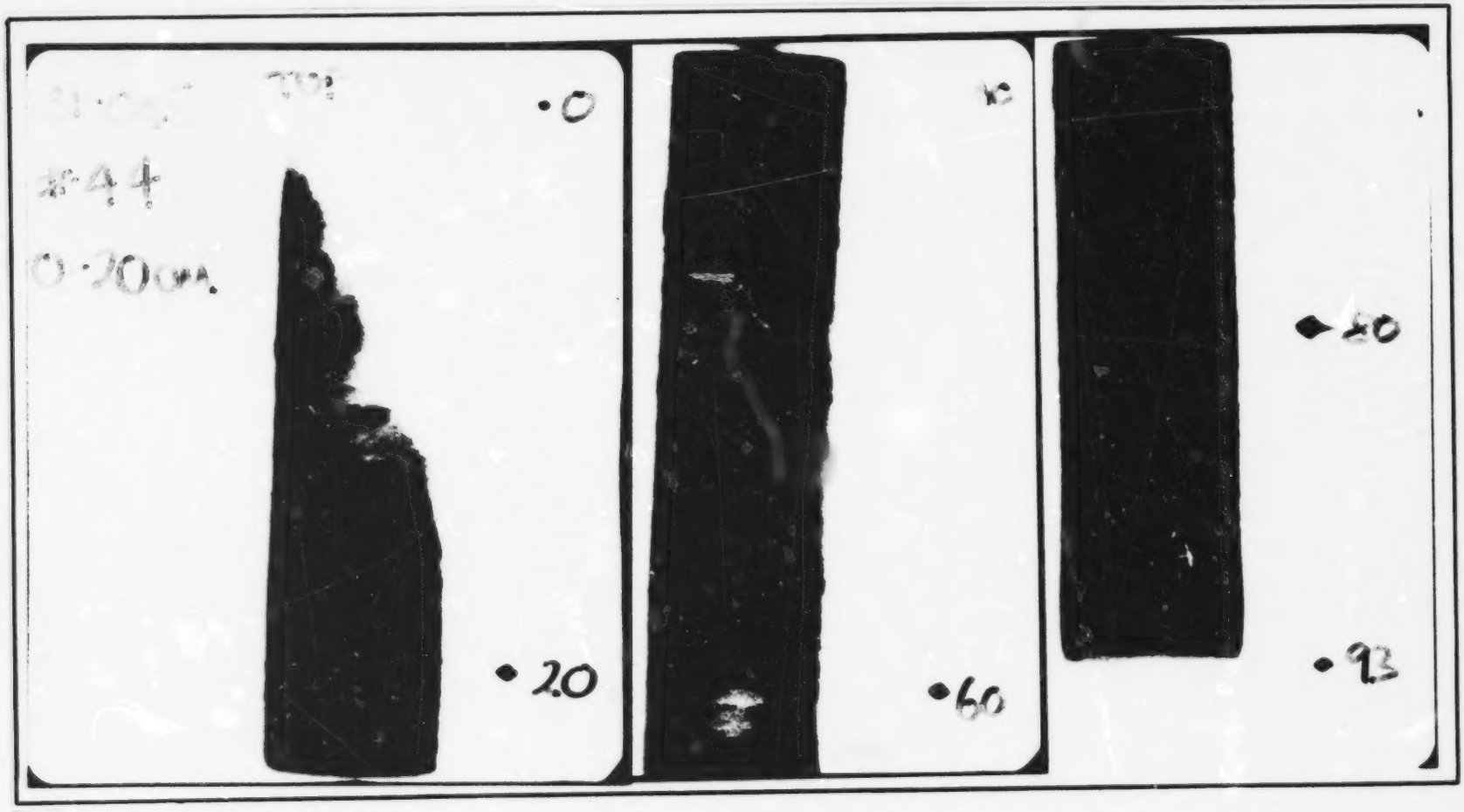


Figure 22 X-rays of cores #44 and #45 from the Hekja Wellsite area.

microfaunal content, visual observations were made of the washed sediment.

Samples 44B and 44C (Tables 1 and 2) were collected from the top of the core barrel and from the tip of the piston core barrel. The textural analysis indicates that the clay and silt fraction increase dramatically down core. Although gravel appears to be randomly distributed throughout the core, it does not form a significant fraction. Three distinctive sedimentary units were identified, their description is discussed in conjunction with the microfaunal analysis.

MICROFAUNAL ANALYSIS

Open marine microfaunal studies are few for this sector of the eastern Canadian Continental Shelf and have generally been in the inter-tidal and adjacent land areas of Baffin Island (eg. Miller, 1975; Feyling-Hanssen 1976(a); 1976(b)). More recent open marine studies which complement the land based work with reference to the areas' Quaternary history include those of Mudie (1981), Aksu (1981), and Osterman (1982) who worked on cores and sediment grab samples from Frobisher Bay, and off Resolution Island (Figure 1).

Osterman (1982) in her work, reports a 'continuous [sedimentation] cycle for the past 27,225 ± 1250 years', with a period of glaciation (the Hall advance of 11,000 years BP), during this time interval off Resolution Island. During the Hall advance she found a characteristic low diversity foraminiferal assemblage, predominantly of **Elphidium excavatum** f. **clavatum** (Cushman), reflecting a sub-ice shelf environment. She also stated that microfaunal and sedimentological evidence from the upper part of the cores indicated that the present day, cold Baffin-Labrador current did not become established until after 5,000 years BP. Prior to this and until about 30,000 years BP, the coast of Baffin Island was under the general influence of the warmer proto-West Greenland current, a view earlier put forward by Aksu (1981).

Laboratory Procedures

After the cores from the Hekja wellsite had been x-rayed,

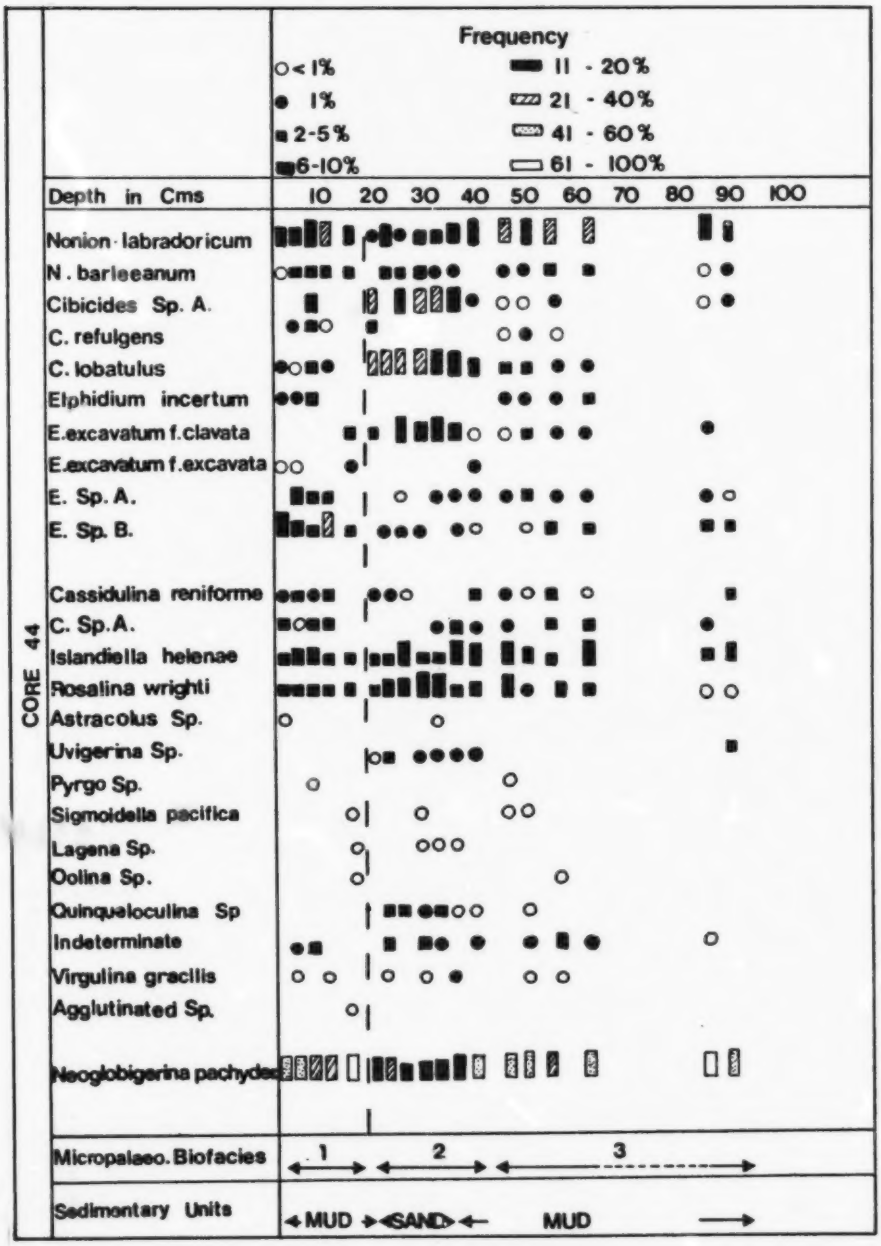


Figure 23 Foraminiferal frequency distribution for core #44. Also included are the corresponding sedimentary units.

they were split into two halves lengthwise. One centimetre thick sediment slices were extracted from the cores at 5 cm intervals. Where rapid changes in lithology and/or colour occurred, additional samples were collected.

Each sample was disaggregated by immersion in cold water for about 10 minutes. The sample was then washed through two sieves of 250 micron (0.25 mm) and 63 micron (0.063 mm) size. The residues left upon each screen were collected, dried on filter paper and then stored in vials.

All the foraminiferal specimens from the 0.25 mm fraction were counted and if necessary an additional number from the 0.063 mm fraction were counted to make up the minimum of 300 required for a valid statistical analysis ('vide' Boltovskoy and Wright, 1976). In samples where the foraminifera were less abundant the whole foraminiferal content was counted. The stratigraphic succession of the two cores are illustrated in Figures 23 and 24.

Foraminiferal biofacies

Three biofacies units are recognizable based upon species occurrence and frequency occurrences of foraminifera in the core samples. These biofacies are most clearly evident in core #44. In core #45, which is a short core of 30 cm, only the first (upper) biofacies unit is clearly distinguishable.

In core #44, the number of specimens and the species diversity (= number of species per sample) remains relatively high and fairly constant throughout the core. However in core #45 the decrease is very rapid. The three biofacies in core #44

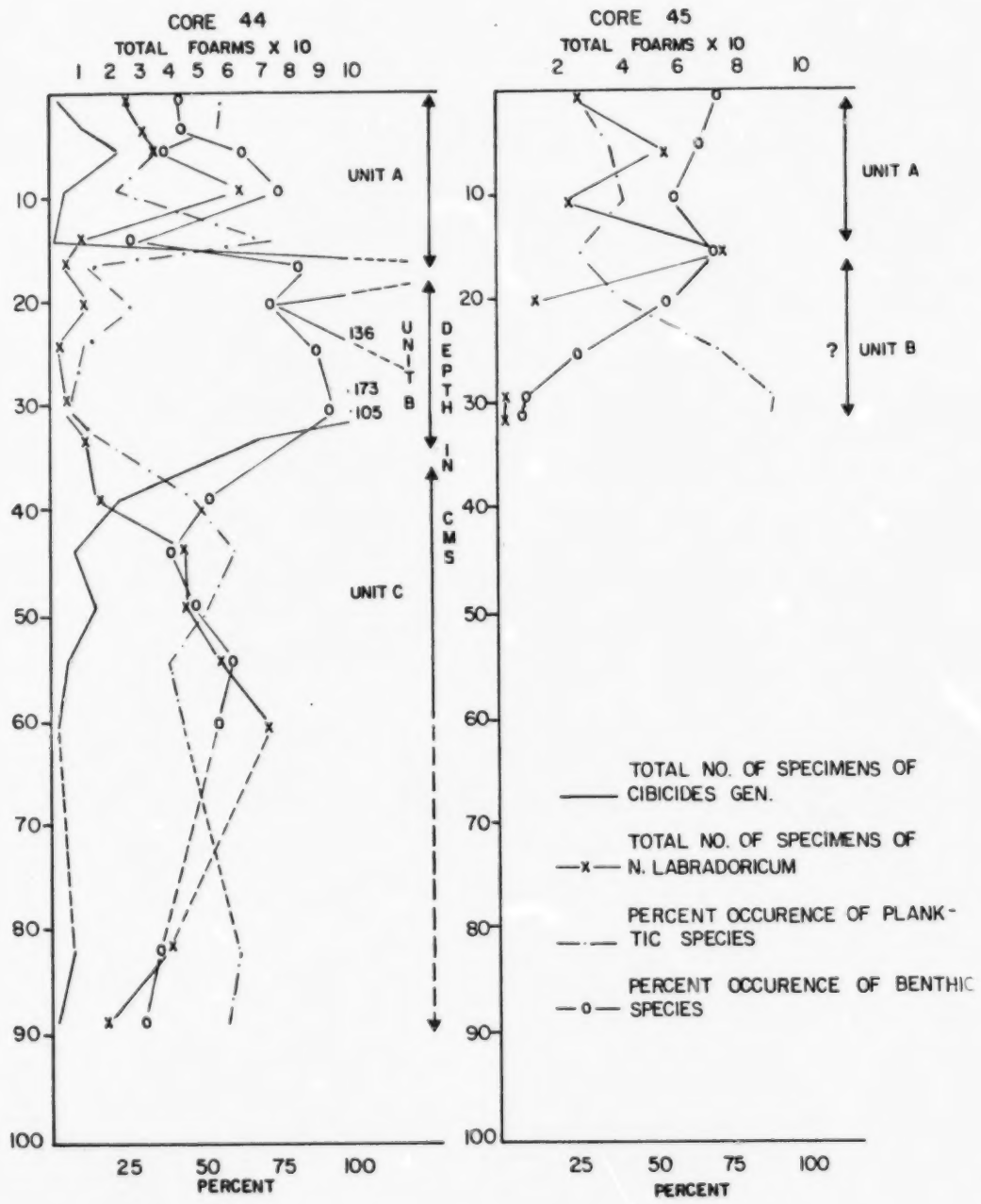


Figure 24 Range chart of selected planktonic and benthic species for cores #44 and #45.

are characterized by the following dominant foraminifera genera (Figure 23):

Biofacies 1 - **Elphidium Nonion Islandiella** - upper unit

Biofacies 2 - **Cibicides** - middle unit

Biofacies 3 - **Nonion Islandiella** - lower unit

Biofacies 1: Elphidium Nonion Islandiella

This biofacies unit occurs at the top of cores #44 (0-20 cm) and #45 (0-18 cm) and is characterized by the occurrence of the benthic foraminifera genera **Nonion** de Montfort, **Elphidium** de Montfort and **Islandiella** Nørvang. The characteristic species of this unit are **Elphidium incertum** (Williamson), **Elphidium** Sp. B along with **Islandiella helenae** Feyling-Hanssen and Buzas, and **Nonion labradoricum** (Dawson). Other less common species of this unit are **Nonion barleeanum** (Williamson), **Cassidulina reniforme** (Nørvang) and **Rosalina wrighti** Brady.

Associated with this benthic assemblage is the planktonic foraminiferal species **Neogloboquadrina pachyderma** (Ehrenberg). This species forms a relatively high percentage of the total assemblage varying from 58% at the top to 71% at the bottom of this unit (Figure 23).

Species belonging to the genus **Elphidium** have generally been recorded in waters shallower than 100 m; however, the species can also be found in large numbers down to a shelf edge environment (ca. 200 m). In contrast, the moderate occurrence of **N. barleeanum** is indicative of deep water environments (Feyling-

Hanssen, (1976,a). In this deep water shelf zone, the species **N. labradoricum** has a higher occurrence than **N. barleeanum** (Figure 23) indicative of present water depths and temperature. The species diversity in this sample is 13.

Biofacies 2: Cibicides

This biofacies is characterized by the occurrences of **Cibicides** Sp.A and **Cibicides lobatulus** (Walker and Jacob); these are associated with one smaller species of the same genus, **Cibicides refulgens** (de Montfort). The latter species is a good indicator of cool to cold water environments (Cushman, 1931); whereas the former has a geographically worldwide distribution (Pereira, 1979). Species from the genus generally inhabit areas of strong bottom currents, associated with coarse to fine grained sediments in the shallow continental water environments. Other species associated with **Cibicides** gen. in this zone, include **Rosalina wrighti** and **Elphidium** Sp. B. Also occurring, but to a much lesser extent are specimens of **Islandiella helenae, Elphidium excavatum** f. **clavatum, Elphidium** Sp. **A.** and a few miliolid specimens belonging to the genus **Quinqueloculina** d'Orbigny. The species diversity in this biofacies increases marginally over that of biofacies 1, to 15.

This biofacies exhibits a sharp drop in the percentage of the planktonic species, **Neogloboquadrina pachyderma** coupled with a corresponding increase in the benthic assemblage (Figure 23). Benthic specimens average about 85% with the planktonic specimens averaging 15%. As a rule of thumb, benthic species dominate

foraminiferal assemblages in shallow water environments and biofacies 2 may reflect this phenomenon, i.e. a shallow water environment.

However, work to date on other cores from this region do tend to indicate otherwise (Osterman, 1982; Aksu, 1981; Fillon and Duplessy 1980). A more likely answer is that this assemblage could be an artifact brought about by scouring icebergs and the subsequent winnowing of finer material (and associated foraminifera). The species **Elphiduim excavatum f. clavatum** does have a high occurrence in this unit (Figure 23). Osterman (1982) finds this species chiefly associated with a low diversity foraminiferal assemblage which reflects a sub ice shelf environment, contiguous with the Hall advance of 11,000 B.P.; however, it is unlikely that this relationship is valid here due to the different geological time periods involved in the two analyses (i.e. shallow Hekja cores versus deeper and longer Resolution Island cores).

Biofacies 3: Nonion Islandiella

The foraminiferal assemblage of this biofacies is similar to that of biofacies 1, however biofacies 3 assemblage may possibly represent a slightly deeper water environment than that indicated in biofacies 1.

Biofacies 3 is dominated by the occurrence of benthic specimens belonging to the genus **Nonion** and **Islandiella** and by the planktonic species **Neogloboquadrina pachyderma** (Figures 23 and 24). The benthic species that characterise this zone are **I.**

hellenae and **N. labradoricum.** Other species associated with them in this unit are **Elphidium** Sp. A, **Elphidium** Sp. B, **Cibicides lobatulus, Cassidulina Sp. A and N. barleeanum; Neogloboquadrina pachyderma** constitute approximately 50% of the assemblage. The species diversity of 15, is the same as in biofacies 2, but higher than that of biofacies 1. A deeper environment is suggested by the greater abundances of planktonic specimens and the species **N. labradoricum.**

Discussion

Without the requisite radiometric dates and amino-acid ratio values, it is not possible to assign 'absolute' ages or to correlate the various sampled levels of the cores collected from the Hekja Wellsite survey area. It should be pointed out that, however accurate a picture radio-carbon dates may establish, problems do exist associated with ^{14}C dates of organic sediments. (Litherland, 1980; Osterman, 1982).

The only other way to assign probable time marker horizons to the Hekja cores is to compare the results obtained at Hekja with those of other workers from nearby, adjacent areas. Osterman (1982), recorded foraminiferal assemblages from sections of her cores that are similar with occurrences from the Hekja area and the Hekja results are compared directly with her results.

The sites of the Hekja and core #HU77-156 (Osterman, 1982) are 85 km apart from opposite slopes of a submarine valley that leads out from Frobisher Bay (Figure 1) Examination of the

seismic data presented by Osterman (1982) indicates that the core site has apparently not been scoured by icebergs; this is in sharp contrast to the Hekja site, where the seabed is heavily scoured. Osterman ('op. cit.') reports 'a continuous record' for the core and by implication that continuous sedimentation has occurred since 27,225 ± 1250 years BP (recent radiocarbon analysis give a fresh data of 18,000 years BP (MacLean, per. comm. 1984)), which is the date attributed to the bottom of the core (Figure 25). This being the case, the core is used as a standard to which the Hekja cores can be compared.

Osterman (1982) records an initial **Islandiella helenae, Cibicides lobatulus** zone, which is not evident in the Hekja cores although there is a high occurrence of **Islandiella helenae** in the top section of Hekja core #44. She does record a **Nonion labradoricum** zone which is almost similar to biofacies 1 and 3 from Hekja. Similar results have been recorded by Vilks and Rashid (1976) on the Scotian Shelf as reported by Osterman ('op. cit.'), Leslie (1965) from Hudson Bay and Fillon and Duplessey (1980) from the Labrador Sea. The higher occurrences of **N. Labradoricum** can apparently be related to the reinstitution of the higher salinity, colder, CO_2- rich water, originating in the Arctic Ocean; this reinstitution occurred only after the sea level rose sufficiently and ice was removed from the troughs of the Queen Elizabeth Islands (Osterman, 1982; pp.171-175). Osterman ('op. cit.') who records high occurrences of **Nonion** gen. attributes a date of 4600 years BP for the first abundant occurrence of this genus.

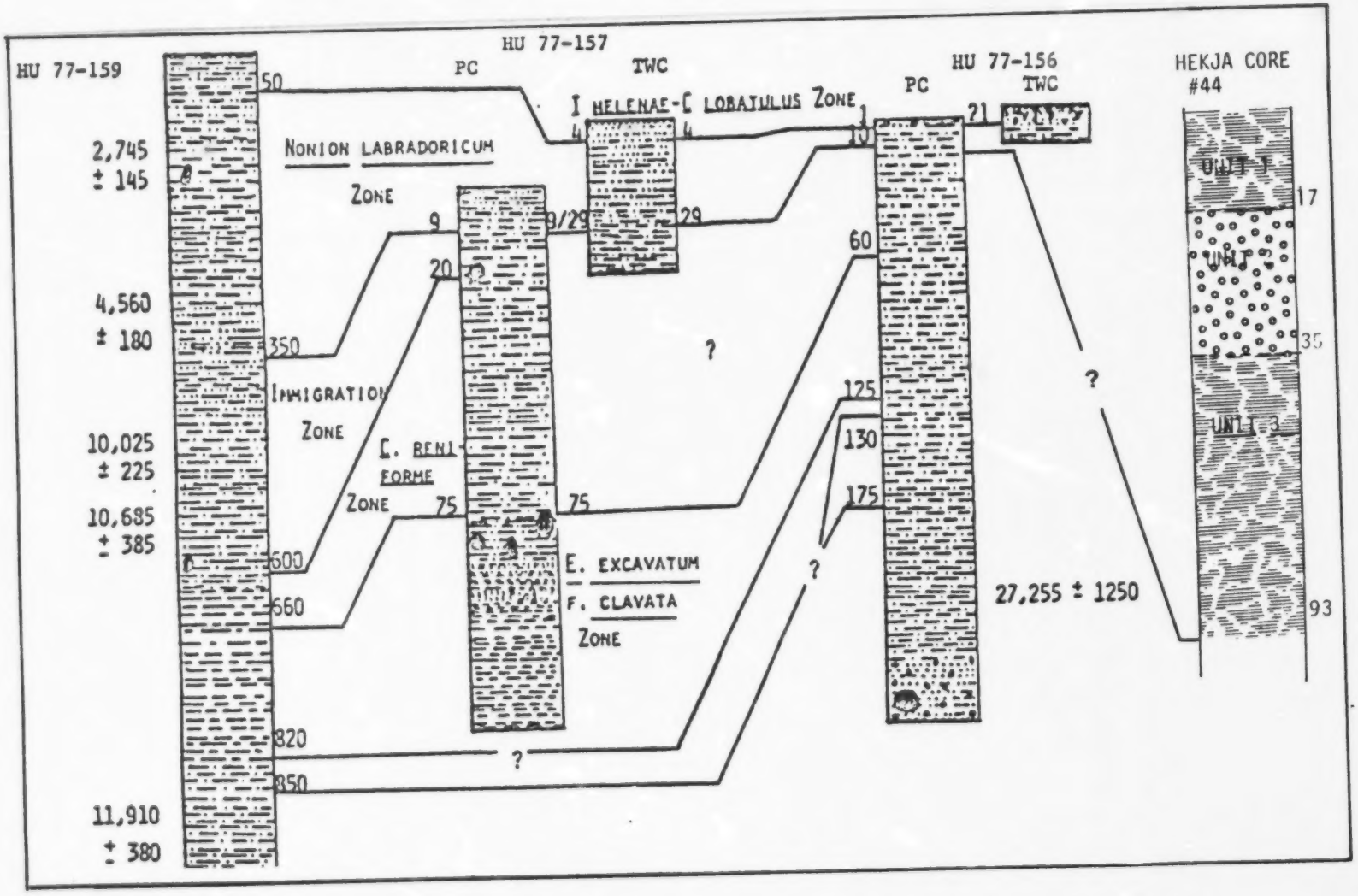


Figure 25 Suggested correlation of the foraminiferal zonation of the three cores, HU77-156, HU77-157 and HU77-159 as well as Hekja core #44.

The two cores (Hekja #44 and HU77-156) have marked microfaunal and sedimentological similarities; however, the cores differ markedly in three aspects:

i) The surficial species from Hekja differ from those off Resolution Island and Frobisher Bay - this however, may be a sampling artifact ('vide' Boltovskoy and Wright, 1976).

ii) Osterman (1982) records very few planktonic specimens in the top sections of the core - in the Hekja vicinity, they are abundant.

iii) The Hekja core shows a marked and abrupt change in species content and sediment texture between 18 and 35 cm (Figure 23) - the sediment in biofacies 2 (i.e., core #44), is a medium to fine sand with very microfaunal specimens of a corresponding size; very few planktonic specimens are found in this biofacies.

The sediment and microfaunal data collected begs a number of likely explanations for the abrupt changes seen in Unit 2 (Figure 23). Three alternatives are considered, and of them, the explanation referring to a scouring event is the most promising.

The first explanation is considered in the context of a scouring event. Unit 2 of core #44 (Figure 23), and the associated coarser sediment do not appear to have a corresponding analogue in any of the other cores studied in this area. It is suggested that this coarse layer of sand is a lag deposit subsequent to scouring and current winnowing. From submersible observations on the Labrador shelf Josenhans and Barrie (1982), noted a number of lag gravel deposits which were relict scour

berms. They distinguished old from young berms by the absence of fine sediments which have been winnowed away.

Observations of the sizes of the foraminiferal tests extracted from the cores with that of the sediment grain sizes, indicate that the two are probably in hydraulic equivalence ('vide' Grabert, 1971). Since this could tend to indicate the lag nature of the deposit, it thus supports the notion that this unit of the core represents a scoured lag deposit from either the scour berm or from the disturbed sediment zone (Figure 2).

Another possible process which could produce similar results is a rapid change in the sediment distribution. Patterns of sediment distribution can vary considerably within a region, e.g. the Southern Grand Banks (Sen Gupta and McMullen, 1969). Sediment distribution patterns reflect a number of primary environmental factors including reworking of relict sediments, sediment input from different source areas, etc. Dynamic changes in the current regime or a cut off of sediment from the source areas may cause a different sediment distribution pattern to develop and transgress the old pattern as is sometimes seen in shelf environments ('vide' Friedman and Saunders, 1978; Bouma 'et al.', 1982). Where this occurs, sudden changes are seen in the depositional record. In principle the changes seen in the Hekja core may reflect this situation. In this case the development of a transgressive ice field could perhaps cut off a sediment source, alternatively it may alter the physical regime. Any of, or a combination of these occurrences could bring about the desired result. It is not known if the sand layer found in core

#44 is regional in its distribution; and until such time that further supporting evidence can be put forward, this mechanism is discounted.

The last mechanism considered involves localized sediment failure. Average seafloor gradients on continental slopes are between 2° and 6° (Dobson 'et al.', 1981). Although such slopes seem insignificant, large-scale failures occur on seafloor gradients as low as 0.6° in some areas. Sediment will generally be deposited wherever slumping occurs and downslope from these areas. Microfauna in the slumped material similarly would be deposited in a random or sequential order depending upon the distance of the depositional site from the zone of the failure. Although slope gradients in Hekja exceed 1°, it is unlikely that localized slumping of sediment has occurred and hence this mechanism is also discounted.

Figure 25 shows a correlation of the foraminiferal zonation of the Hekja core compared with those of Osterman (1982). The correlation suggests that the entire length of core #44 is comparable to that of the **Nonion labradoricum** zone defined by Osterman ('op. cit.') which has a maximum radiocarbon date of 4560 ± 180 years B.P. Assuming that biofacies 2 represents a scouring event and that the bottom of core #44 is of an equivalent age to the bottom of the **N. labradoricum** zone of Osterman ('op. cit.') then from extrapolation of these results, it is suggested that the bottom of biofacies 3 of the Hekja core has a maximum age of 5000 years BP. Hence it may be concluded

that biofacies 2 in Hekja core #44 is younger than 5000 years BP and probably older than 2000 years BP.

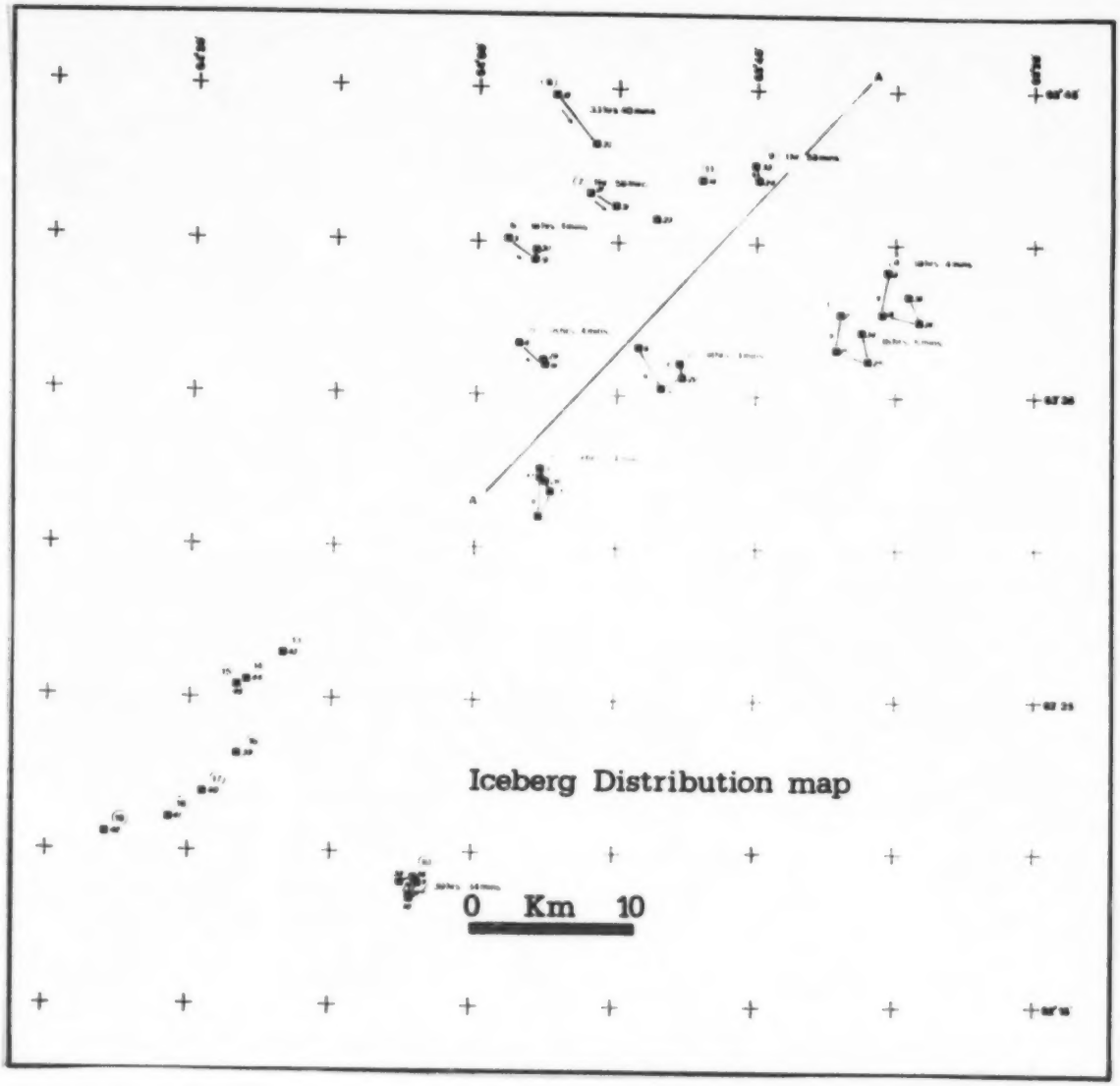


Figure 26 Map showing iceberg distribution in the survey area, off southeast Baffin Island.

ICEBERG STUDIES

During the Hekja survey an iceberg log was kept. The purpose of keeping the log was:

i) to note iceberg motion during the survey and

ii) to observe the distribution of icebers in the area during the survey.

A total of 42 observations were made using the ship's radar. From these observations an iceberg distribution map was compiled (Figure 26). Arrows indicating movement direction for each iceberg are shown and the amount of time elapsed between the first and last observations (where more than one observation was made) is given (Figure 26).

Iceberg Motion

Nineteen icebergs have been identified from the sitings and these are numbered in Figure 26. Ten icebergs were observed more than once.

Icebergs 1-4 have tracks that indicate an anticlockwise spiral movement, whilst icebergs 5-8 have trajectories which indicate a net southeasterly movement. Icebergs 5 and 6 shows indications of beginning anticlockwise spirals. Iceberg 9 shows an apparent northwesterly movement and iceberg 10 (located at bottom of Figure 26) shows erratic movement. Clockwise spiral trajectories have been observed for icebergs on the Labrador shelf (e.g. Ball 'et al.', 1980 and Barrie 'et al.', 1981).

It is interesting to note that icebergs 1-4, which show spiral trajectories, occur southeast of a northeast-southwest oriented line; A-A^1 separates them from icebergs 5-9, which show

dominantly straight trajectories (Figure 26). It is possible that this line indicates the boundary between two localized current regimes. The observations for iceberg number 10 cluster significantly indicating that this iceberg was probably motionless during the observation time (39 hours 34 mins.) and may possibly have been grounded. The water depth in this region is between 125-140m.

Iceberg Distribution

Icebergs were distributed in a broad band trending roughly northeast-southwest (Figure 26). Icebergs 1 - 9 and 11 and 12 all fall to the north of the surveyed area (Figure 3 and 26). Iceberg 10 and icebergs 13 - 19 occur within the surveyed area. It is interesting to note that the latter group of icebergs is located in a line which corresponds roughly with the abrupt change in slope between 65 - 95 m in the northwestern part of the area (Figures 3 and 26). Unfortunately, because only one observation was made of each iceberg there is no evidence to show whether they were moving or stationary.

SUMMARY RESULTS

1. A buried regional angular unconformity (Tertiary in age) has been identified in the survey area with a minimum burial depth of 2 m and a maximum burial exceeding 5 m. Penetration of iceberg keels to the unconformity has probably occurred in both the Hekja Wellsite and Hekja North areas. Evidence for this in Hekja North is shown on the sidescan mosaic as hummocky relief in scour troughs which may represent large blocks of sediment which have been disrupted from below the unconformity. This evidence is not seen in the Hekja Wellsite area probably because scours have been partially infilled.

2. Using cross-cutting techniques, 8 relative age groups of scours have been identified in both the Hekja Wellsite and Hekja North mosaic areas. In the Hekja Wellsite area, 1 oldest (group 8) and 3 youngest (group 1) scours have been identified. In the Hekja North area, 1 oldest (group 8) and 2 youngest (group 1) scours have been identified.

If datable material could be retrieved from the troughs of these scours it could be possible to determine:

i) the average minimum absolute ages for the oldest scours;

ii) the average minimum absolute ages of the youngest scours; and

iii) a scouring rate for the two areas.

Results from Hekja Wellsite and Hekja North could then be compared.

3. Mean scour depth for Hekja wellsite is 1.10 m - shallower than mean scour depth for Hekja North which is 1.27 m. This was not expected because deeper scours usually occur in deeper water. However, the observation that deeper scours occur in deep waters was based on data from shallower areas in the Beaufort Sea and Labrador Shelf; this principle may not necessarily hold true for the Hekja area (275 - 350 m). Changes in geotechnical properties and preferential infilling of scours in the Hekja wellsite area are suspected.

4. A geomorphic feature which has been interpreted as a mud volcano by Woodworth-Lynas (1983,a) was identified from the seismic survey results in a water depth of 320 m. It is located above a major geological contact zone (Precambrian/Cenozoic) and because the smooth-sided cone is located on a thoroughly scoured seabed, the features is inferred to be of recent origin.

5. Two distinct gross sedimentary facies can be distinguished for the survey area. Area 1, occupies the northwestern section in waters shallower than 150 m and the second area occupies the southeast section in areas deeper than 150 m. The northwest area is dominated by sand or gravel with negligible amounts of fines. The underlying bedrock appears to outcrop in places and sediment cover is very sparce. The southeast section varies texturally from little gravel to almost 100% gravel underlain by fine muds.

6. Three biofacies units can be identified from core #44. Correlating the Hekja cores with core #HU77-156 from off Resolution Island indicates that the total time span of the Hekja core is probably not much more than 5000 years. Although there are a number of possible explanations for this, the most probable one is that the Hekja core was collected from either the trough or the berm of an iceberg scour. The age of this event in the core is put at not older than 5000 years BP and no younger than 2000 years BP.

7. Nineteen icebergs were observed during the survey, the variable movements of which indicate the possible existence of a boundary between two different current regimes. One iceberg (#10) was inferred to have been grounded for the period of its observation (39.5 hours) in a water depth of 125-140 m.

RECOMMENDATIONS

Field measurements and data analysis as outlined in the project proposal have been generally successful. Analysis of seabed sediment stability is not feasible at present without the relevant current and tidal data. Radiometric dating of biogenic material has been delayed due to other priorities of the laboratory which is undertaking the analysis.

The results of this investigation indicate that additional seabed data is required in order to develop a comprehensive geological picture of the Hekja Wellsite area. Based on the results of this work we recommend the following:

1. that datable material be retieved from selected scour troughs to ascertain average minimum absolute ages of the oldest and youngest scours. This will enable a scouring rate for the Hekja area to be derived;

2. that core samples be taken from the seabed feature identified as a mud volcano to ascertain if it is recent or relict;

3. that core samples, based on a grid pattern, should be collected in order to substantiate the preliminary micropalaeontological results obtained from the two cores;

4. that surface grab samples be collected along a grid of 5 km spacing to develop a comprehensive understanding and a realistic model of the sediment dynamics of the seabed in the Hekja and Raiegh wellsite areas; and

5. that bottom current data from the area be collected to supplement the sediment dynamics study;

6. that geotechnical analysis of some of the cores from the sampling grid be carried out to develop a 3-D sediment dynamics model for the surficial sediments.

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